A11102 163058

NAT'L INST OF STANDARDS & TECH R.I.C.

A11102163058

/Technologic papers of the Bureau of Sta
T1 .U4 V51-57;1915 C.1 NBS-PUB-C 1910

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 55

SPECIAL STUDIES IN ELECTROLYSIS MITIGATION

IV. A PRELIMINARY REPORT ON ELECTROLYSIS MITIGATION IN ELYRIA, OHIO, WITH RECOMMENDATIONS FOR MITIGATION

BY

BURTON McCOLLUM, Electrical Engineer

and

K. H. LOGAN, Assistant Physicist

Bureau of Standards

ISSUED JANUARY 22, 1916

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

TECHNOLOGIC PAPERS

1. The Effect of Preliminary Heating Treatment upon the Drying of Clays (53 pp.) ... *A. V. Bleininger*
2. The Strength of Reinforced Concrete Beams—Results of Tests of 333 Beams (first series) (200 pp.) ... *R. L. Humphrey and L. H. Losse*
3. Tests of the Absorptive and Permeable Properties of Portland Cement Mortars and Concretes, Together with Tests of Damp-Proofing and Water-Proofing Compounds and Materials (127 pp.) ... *R. J. Wig and P. H. Bates*
4. The Effect of Added Fatty and Other Oils upon the Carbonization of Mineral Lubricating Oils (14 pp.) ... *C. E. Waters*
5. The Effect of High-Pressure Steam on the Crushing Strength of Portland Cement Mortar and Concrete (25 pp.) ... *R. J. Wig*
6. The Determination of Chromium and Its Separation from Vanadium in Steels (6 pp.) ... *J. R. Cain*
7. The Testing of Clay Refractories, with Special Reference to Their Load-Carrying Capacities at Furnace Temperatures (78 pp.) ... *A. V. Bleininger and G. H. Brown*
8. A Rapid Method for the Determination of Vanadium in Steels, Ores, etc., Based on Its Quantitative Inclusion by the Phosphomolybdate Precipitate (20 pp.) ... *J. R. Cain and J. C. Hostetter*
9. Density and Thermal Expansion of Linseed Oil and Turpentine (27 pp.) ... *H. W. Bearce*
10. Melting Points of Fire Bricks (17 pp.) ... *C. W. Kanolt*
11. Comparison of Five Methods Used to Measure Hardness (27 pp.) ... *Ralph P. Devries*
12. Action of the Salts in Alkali Water and Sea Water on Cements (157 pp.) ... *P. H. Bates, A. J. Phillips, and R. J. Wig*
13. The Evaporation Test for Mineral Lubricating and Transformer Oils (13 pp.) *C. E. Waters*
14. Legal Specifications for Illuminating Gas (31 pp.) ... *E. B. Rosa and R. S. McBride*
15. Surface Insulation of Pipes as a Means of Preventing Electrolysis (44 pp.) ... *Burton McCollum and O. S. Peters*
16. Manufacture of Lime (130 pp.) ... *W. E. Emley*
17. The Function of Time in the Vitrification of Clays (26 pp.) ... *G. H. Brown and G. A. Murray*
18. Electrolysis in Concrete (137 pp.) ... *E. B. Rosa, Burton McCollum, and O. S. Peters*
19. Physical Testing of Cotton Yarns (31 pp.) ... *W. S. Lewis*
20. Determination of Sulphur in Illuminating Gas (46 pp.) ... *R. S. McBride and E. R. Weaver*
21. Dehydration of Clays (23 pp.) ... *G. H. Brown and E. T. Montgomery*
22. Effect of Overfiring upon the Structure of Clays (23 pp.) ... *A. V. Bleininger and E. T. Montgomery*
23. Technical Control of the Colloidal Matter of Clays (118 pp.) ... *H. E. Ashley*
24. Determination of Phosphorus in Steels Containing Vanadium (11 pp.) ... *J. R. Cain and F. H. Tucker*
25. Electrolytic Corrosion of Iron in Soils (69 pp.) ... *Burton McCollum and K. H. Logan*
26. Earth Resistance and Its Relation to Electrolysis of Underground Structures ... *Burton McCollum and K. H. Logan*
27. Special Studies in Electrolysis Mitigation (55 pp.) ... *E. B. Rosa and Burton McCollum*
28. Methods of Making Electrolysis Surveys ... *Burton McCollum and G. H. Ahlborn*

[Continued on p. 3 of cover]

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, Director

No. 55

SPECIAL STUDIES IN ELECTROLYSIS MITIGATION

IV. A PRELIMINARY REPORT ON ELECTROLYSIS MITIGATION IN ELYRIA, OHIO, WITH RECOMMENDATIONS FOR MITIGATION

BY

BURTON McCOLLUM, Electrical Engineer

and

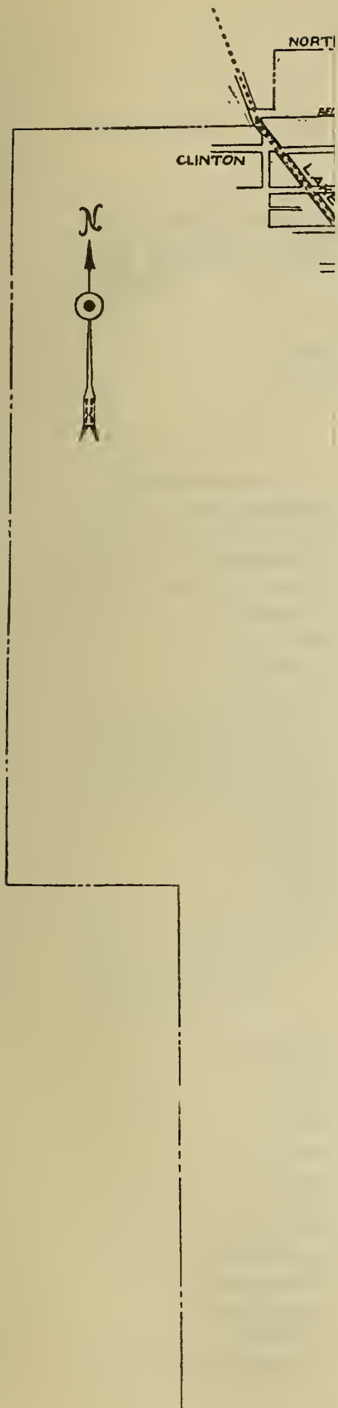
K. H. LOGAN, Assistant Physicist

Bureau of Standards

ISSUED JANUARY 22, 1916

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
20 CENTS PER COPY


NORT
CLINTON

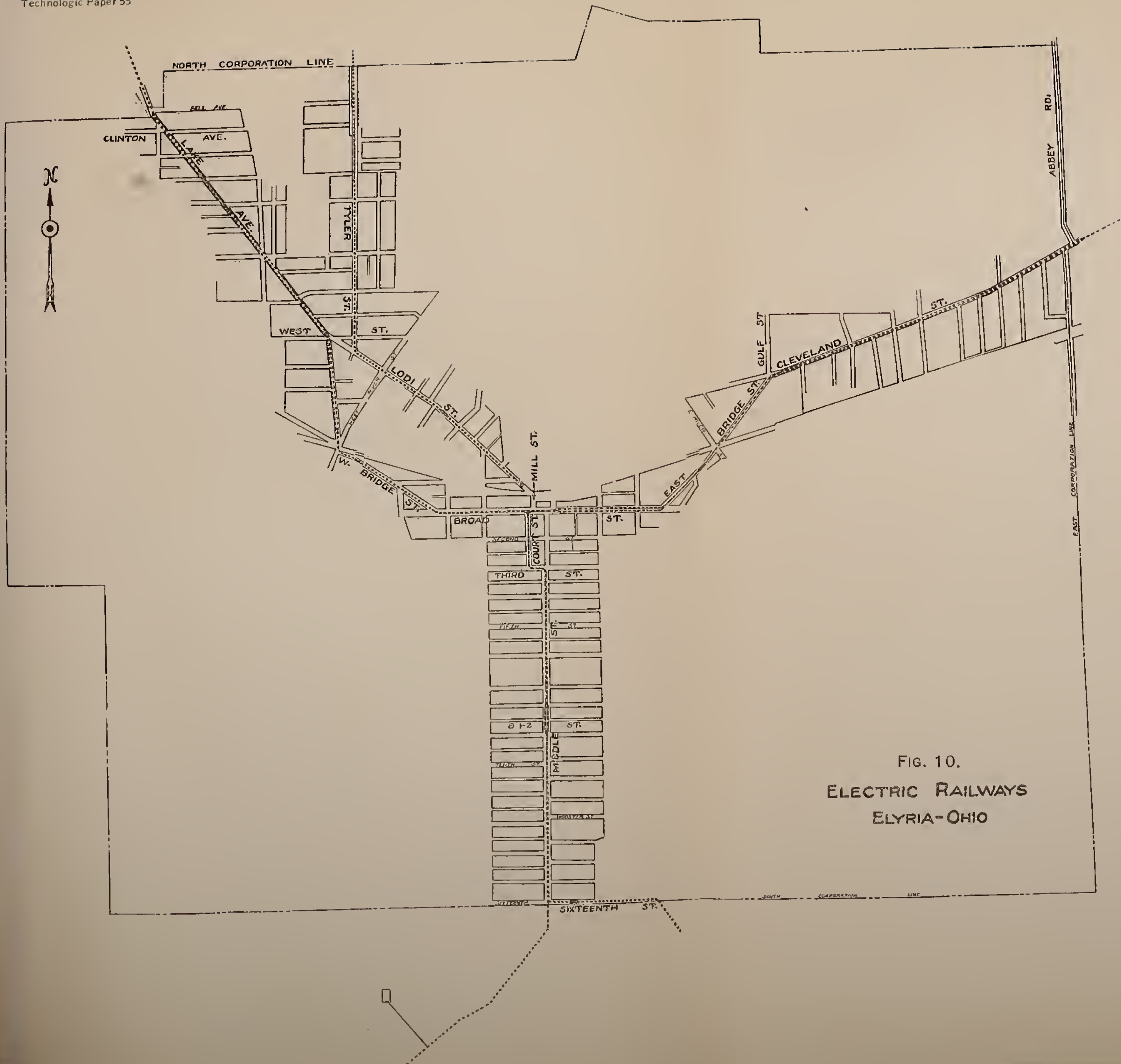


FIG. 10.
ELECTRIC RAILWAYS
ELYRIA-OHIO

SPECIAL STUDIES IN ELECTROLYSIS MITIGATION

IV. A PRELIMINARY REPORT ON ELECTROLYSIS MITIGATION IN ELYRIA, OHIO, WITH RECOMMENDATIONS FOR MITIGATION

By Burton McCollum and K. H. Logan

CONTENTS

I. INTRODUCTION

In January, 1914, the Bureau of Standards received a letter from the deputy clerk of Elyria, Ohio, asking for information relative to the electrolysis investigations of the Bureau and requesting assistance in drafting a law regulating electrolysis in the city of Elyria. In response to this letter one of the present authors was sent to Elyria to confer with the city officials in regard to the subject of electrolysis in Elyria. At that conference the Bureau's representative advised against immediate legislation, recommending instead that an engineering investigation of the subject be made, and that the results should be used as a basis for future action on the part of the city and the utilities interested in the local electrolysis situation. This suggestion was adopted and the city officials of Elyria arranged for a conference between the representative of the Bureau and officials of the Cleveland, Southwestern & Columbus Railway Co. This conference was held on the afternoon of February 13 in the offices of the company in Cleveland. Arrangements were made whereby the railway company would cooperate with the Bureau of Standards in making a careful study of electrolysis in Elyria and vicinity. With a view of determining what measures should be taken for reducing electrolysis troubles to a reasonable minimum, it was arranged that the railway company would furnish all information that might be required in regard to the physical condition of their plant, and this information was later supplied in response to a formal request by the Bureau of Standards.

In view of the fact that the railway officials did not have available any recent test data showing the electrical conditions prevailing in the track return and underground pipe systems in Elyria, a request for data of this character was made to the city officials, and the latter arranged with the Logan Natural Gas & Fuel Co., which supplies natural gas to Elyria, to make an electrolysis survey and provide the Bureau with such information as might be required in regard to the present electrolysis conditions. This survey was made during the latter part of March, 1914, by R. B. Burr, representing the Logan Natural Gas & Fuel Co., and shortly thereafter the data obtained were forwarded to the Bureau of Standards.

II. PRESENT ELECTROLYSIS CONDITIONS IN ELYRIA

1. OVER-ALL VOLTAGE CONDITIONS

The most important of these test data are presented below. Table 1 shows the over-all potential-difference measurements taken between remote points on the tracks of the two lines within the city of Elyria and between the tracks of the Cleveland, Southwestern & Columbus Railway and the Lake Shore Electric Railway at two places. Table 1 also shows over-all voltage measure-

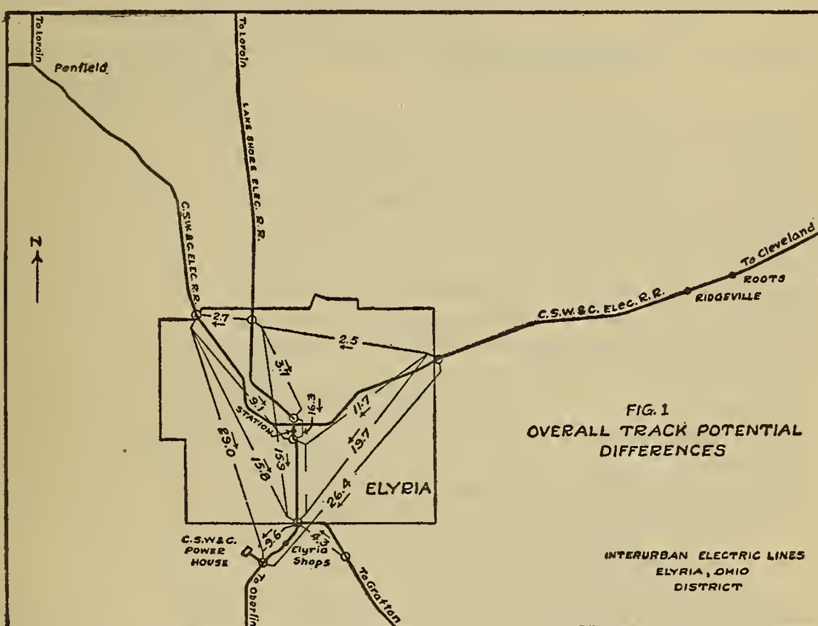


FIG. 1
OVERALL TRACK POTENTIAL DIFFERENCES

ments between the tracks near the power house and the points where the Cleveland, Southwestern & Columbus tracks intersect the corporation line. These measurements are also shown in Fig. 1. The figures shown here, and those that follow, represent the algebraic average values for the period during which the readings were taken. The algebraic average is given because this figure is a better criterion of the actual danger from corrosion of underground structures than any arithmetical average. In most cases the over-all voltage measurements did not cover the full 24-hour period, but for the most part the values given are substantially the same as the 24-hour averages would be, a fact made

evident by comparing the hours covered by the charts with the car schedules of the different lines. In order to give an idea of the range of voltage drop to be expected, we have also given, in Table 1, the values of over-all potential differences for the maximum hour and for the highest 15-minute period, as shown by the recording charts.

TABLE 1

Over-all Potential Measurements, Elyria, Ohio, March 16–21, 1914

A. MEASUREMENTS WITHIN CITY LIMITS

Location of points between which readings were taken. First point positive to second point	Observed average voltages—		
	For period of chart	For maximum hour	For highest 15-minute period
Lake Avenue and north corporation line to Middle Avenue and Sixteenth Street	15.8	30.0	35.0
Lake Avenue and north corporation line to Court Street north of Third Street	9.1	16.0	24.0
Cleveland Street and Abbey Road to Lake Avenue and north corporation line	2.5	11.0	22.0
Cleveland Street and Abbey Road to Court Street north of Third Street	11.7	27.5	32.0
Cleveland Street and Abbey Road to Middle Avenue and Sixteenth Street	19.7	33.0	35.0
Lake Shore Electric Railway at alley north of Clinton to Lake Avenue and north corporation line	2.7	4.9	8.3
Lake Shore Electric Railway at alley north of Clinton to Middle Avenue and Sixteenth Street	15.9	22.0	27.0
Lake Shore Electric Railway at alley north of Clinton to Fremont and Lodi Streets	3.7	5.0	8.0
Fremont and Lodi Streets to Court Street north of Third Street	16.3	42.5	50.0
Court Street north of Third Street to Middle Avenue and Sixteenth Street	7.1	11.0	14.0

B. MEASUREMENTS REFERRED TO TRACKS AT POWER HOUSE

Lake Avenue and north corporation line to tracks at power house	29.0	42.5	50.0
Cleveland Street and Abbey Road to tracks at power house	26.4	40.0	50.0
Middle Avenue and Sixteenth Street to tracks at power house	9.6	16.0	18.0
Cleveland, Southwestern & Columbus Railway tracks at Fuller Street to Middle Avenue and Sixteenth Street	4.3	9.0	12.0

An examination of Table 1 shows that the over-all potential differences reach very high values, the highest average value observed within the city limits being between Cleveland Street and Abbey Road and Sixteenth Street and Middle Avenue. The average value here is 19.7 volts, while the value for the maximum hour is 33 volts, and for the highest 15-minute period 35 volts. Most of the values in the table are seen to be very high, and indicate the necessity for radical reduction in the over-all voltage drops in order to safeguard the underground

pipe and cable systems. A particularly bad condition is found in the vicinity of Broad and Court Streets, where the potential difference between the tracks of the Lake Shore Electric Railway and the Cleveland, Southwestern & Columbus Railway shows an average value of 16.3 volts, while the average for the maximum hour is 42.5 volts, and for the highest 15-minute period 50 volts. Since the distance between these tracks is but a few hundred feet, this represents a very serious condition, which, however, can be easily and cheaply remedied by tying the tracks of the two systems together as indicated later.

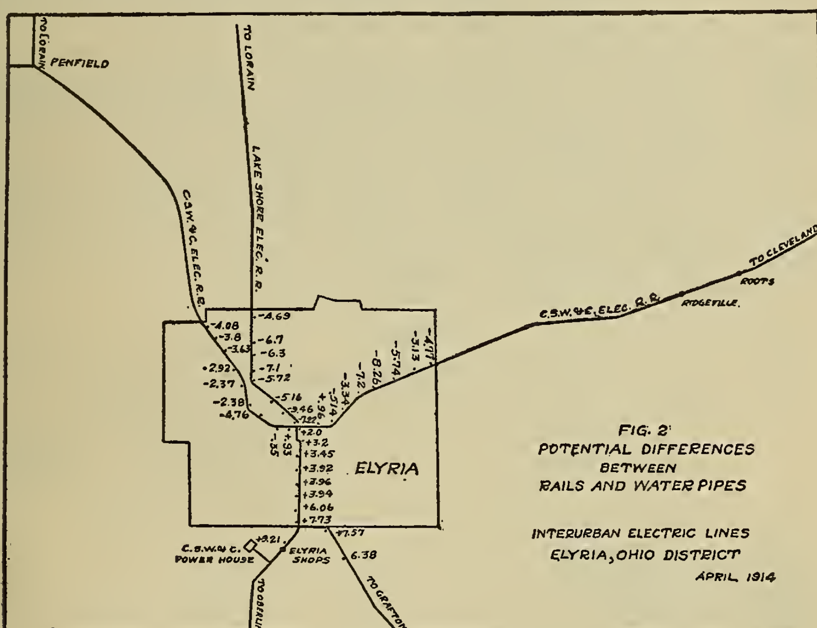


FIG. 2
POTENTIAL DIFFERENCES BETWEEN RAILS AND WATER PIPES

INTERURBAN ELECTRIC LINES
ELYRIA, OHIO DISTRICT
APRIL 1914

2. POTENTIAL DIFFERENCES

The potential differences between pipes and rails given in Table 2 also show very high values, and further evidence the need for improvement in the negative return. The potential differences were for the most part taken for a period of one hour during average load conditions. Table 2 gives the average of both positive and negative readings in each case, and the total duration of the positive and negative readings. The positive sign indicates that the pipes are positive to the tracks. The last

column gives the algebraic average values for the entire period of the test. It is this figure that is most important and the one that has been used in Fig. 2. An examination of Table 2 and Fig. 2 shows that large differences of potential exist between pipes and tracks throughout the greater part of the city. On Lake Avenue, and also on East Bridge Street, the readings reverse repeatedly, but tend toward the negative for the most part, as shown by the column giving the algebraic averages. On Broad Street, however, and the entire region south of there, the pipes have become definitely positive to tracks, becoming more strongly positive as the power house is approached. The values of the potential differences recorded in the positive area south of Broad Street range from 2 to 9 volts, and are so high as to indicate serious danger to the underground metallic structures. While the potential differences are not an absolutely definite criterion as to the danger to the pipes, still, under ordinary conditions, these values should be reduced to at most one-tenth of their present magnitude before we would consider that a reasonably safe condition of the pipes would be assured.

TABLE 2

Potential Differences Between Water Pipes and Rails, Elyria, Ohio, Mar. 17–21, 1914

Location	Observed voltages and time involved		Weighted algebraic averages
	Voltages	Minutes	
Cleveland Street and Abbey Road	−4.77	59	−4.77
Cleveland Street and Beebe Court	−3.13	50	−3.13
Cleveland and Olive Streets	−5.72	52	−5.72
Cleveland and Homer Streets	−8.26	60	−8.26
Cleveland and Gulf Streets	−7.2	58	−7.2
Francis grocery, East Bridge Street	+1.1	4	−3.34
	−3.66	55	
East Broad and East Bridge Streets	+1.8	27	.42
	−2.35	31	
East Broad Street and East Avenue	+2.21	40	+ .965
	−2.35	15	
Broad and Court Streets	+3.33	43	+ .204
	−2.53	12	
Third Street and Cheapside	+3.75	50	+3.2
	−1.79	5½	
Fifth Street and Middle Avenue	+4.08	51	+3.45
	−1.13	7	
Seventh Street and Middle Avenue	+4.38	56	+3.92
	−1.39	5	

TABLE 2—Continued

Potential Differences Between Water Pipes and Rails, Elyria, Ohio, Mar. 17–21, 1914—Continued

Location	Observed voltages and time involved		Weighted algebraic averages
	Voltages	Minutes	
Ninth Street and Middle Avenue	+4.26	49	+3.96
	−1.39	2¾	
Eleventh Street and Middle Avenue	+4.4	55	+3.94
	−1.83	4½	
Thirteenth Street and Middle Avenue	+6.26	54	+6.06
	− .95	1	
Sixteenth Street and Middle Avenue	+7.73	57	+7.73
Fire plug opposite car barns	+9.21	60	+9.21
East Avenue and Sixteenth Street	+7.57	56	+7.57
1375 East Avenue	+7.05	56	+6.38
	−3.6	3¾	
150 feet north of L. S. & M. S. Railway on Lodi Street	−7.22	29	−7.22
West Avenue and Lodi Street	−9.46	35	−9.46
Kaiser Court and Lodi Street	+ .27	2¼	−5.16
	−5.59	27	
50 feet east of L. S. & M. S. Railway curve on Lodi Street	+1.5	5½	−5.72
	−7.33	24	
Erie Street and L. S. & M. S. Railway	+1.15	1	−7.1
	−7.46	25	
Dewey Street and L. S. & M. S. Railway	+1.41	4	−6.3
	−7.51	25	
North 507 Bond Street	+1.36	2¾	−6.7
	−7.54	26	
Belle Avenue and L. S. & M. S. Railway	+1.16	5	−4.69
	−5.86	25	
Lake Avenue and East Erie	+1.6	15	−2.92
	−5.56	26	
Lake Avenue and Dewey Avenue	+1.36	12	−3.52
	−5.34	33	
Lake Avenue and Spruce Street	+1.67	11	−3.63
	−5.41	32	
Lake Avenue and Walnut Street	+1.77	4½	−3.8
	−4.8	25	
Lake Avenue and Woodland Avenue	+1.42	25	−4.08
	−5.35	49	
Broad and Chestnut Streets	+1.56	32	− .354
	−2.85	24	
Water and West Bridge Streets	+1.63	29	− .476
	−2.51	30	
Lake Avenue and West River Street	+1.35	11	−2.38
	−4.16	24	
Lake Avenue and School Street	+1.4	17	−2.37
	−5.01	24	
Broad Street and West Avenue	+2.57	41	+ .93
	−2.61	19	

III. CAUSE AND REMEDY OF PRESENT CONDITIONS

The foregoing data indicate that considerable trouble is to be expected from electrolysis from stray currents under present conditions, and this is borne out by the testimony of city officials and representatives of the gas company to the effect that a good deal of trouble has been experienced. In order to determine whether the trouble is due in any appreciable measure to bad track conditions within the city of Elyria, we have made a comparison of the observed over-all potential measurements with the values calculated from the known load on the lines, assuming perfect bonding of the tracks. The calculated values agree very closely with the observed values, the latter being somewhat smaller, as would be expected, due to leakage from the tracks. The comparison shows beyond doubt that the high voltages are not due primarily to bad track bonding, but to the fact that the rails are being worked at far too high a current density, so that the remedy to be applied must be directed toward taking the current from the tracks at such points as will reduce the potential drop therein to the desired safe limit.

The reduction of potential drops in the tracks in Elyria can best be accomplished by the joint use of three remedial measures. The first and most important of these is the reduction of feeding distances, both in the Cleveland and Penfield branches. The second is the electrical interconnection of the tracks of the Cleveland, Southwestern & Columbus Railway and the Lake Shore Electric Railway at points within the city of Elyria, at which they approach each other closely. The third measure consists in the installation of properly designed insulated negative feeders after the manner described later. The application of these three mitigative measures to conditions existing in Elyria is described in detail later in this report.

1. SHORTENING OF FEEDING DISTANCES

Shortening the feeding distances on both the Cleveland and Penfield branches is of prime importance from the standpoint of satisfactory and economical car operation and electrolysis mitigation. The growth of the traffic on both these lines has reached a

point where it will be necessary very soon, solely on account of operating conditions, to reduce these feeding distances in order to maintain adequate voltages at the cars at a reasonable operating cost. On the Cleveland line the nearest station to the power house is at Rockport, 18½ miles distant. This is too long a feeding distance for the character of the service maintained on these lines, which at present includes an hourly local service each way, a limited car every two hours during the daytime (with occasional extras), and express-car service. It is apparent that the company will shortly find it necessary to install an additional substation between Rockport and Elyria for operating purposes alone, and when this is installed it will greatly simplify and cheapen the mitigation of electrolysis troubles in Elyria. On the Penfield branch the Elyria power house is at present supplying the entire line between Court Street and the Penfield substation. The reason for this is that the Penfield substation has not sufficient capacity to permit it to carry the Amherst and Lorain divisions and also its proper share of the Penfield-Elyria division. This results in the Elyria power house supplying current to this entire line, a distance of over 7 miles. This distance could be reduced very greatly if arrangements were made for supplying half of the Elyria-Penfield division from the Penfield substation. In order to accomplish this, the capacity of the station would need to be increased by about 150 kilowatts, or arrangements made for reducing the amount of power supplied by this station to either the Amherst or the Lorain branches. Either of these plans may be adopted, but the former has been made the basis for the estimates contained in a later part of this report. While 150 kilowatts increase in capacity would be sufficient for present purposes, it is probably not desirable to install so small a unit as this, a larger unit of, say, 300 kilowatts capacity being preferable to allow for future growth of traffic.

The new substation proposed for the Elyria-Cleveland branch should be located preferably somewhere in the vicinity of Chestnut. This is not quite the middle point of the line, but in view of the fact that it is planned to extend the high-tension transmission line from Rockport to the proposed substation it will be more economical to place the station somewhat east of the middle

point between the two present stations. All of the calculations contained in the latter part of this report are based on the assumption that this proposed station is to be located at Chestnut, a distance of about 50 200 feet from the Rockport substation.

The reduction of the feeding distances by the means above indicated yield a number of important benefits. Among these may be mentioned better voltage at the cars, better car lighting, and increased reserve capacity with correspondingly better service insurance. Calculations given in detail will show that the above-mentioned changes in the feeding distances would bring about a reduction of about 70 kilowatts in the total power-loss average for the 24-hour period, which saving has an annual value to the railway company of about $6780. This 70-kilowatt average reduction in power loss corresponds to about 200 kilowatts saving during the maximum-load periods, and this alone gives rise to an increase in reserve capacity of about 200 kilowatts in the present stations. In addition to this the plan contemplates the installation of 600 kilowatts extra station capacity, giving a total of 800 kilowatts net increase in reserve capacity of the plant supplying the Penfield and Cleveland branches.

The shortening of the feeding distances brings about very great improvement in the electrolysis conditions both in Elyria and on the 20-inch main between Elyria and the pumping plant, because it greatly reduces the drop of potential in the rails as well as the length over which these potential drops persist. This reduction in potential drops in the rails further greatly reduces the amount of copper that would otherwise be required in the negative feeder installation in order to bring the potential drops throughout the city of Elyria within safe limits.

In addition to the above, the installation of a new substation at Chestnut makes it practicable to remove one of the present positive feeders extending between the Elyria power house and the point about 8½ miles east on the Cleveland line, since, owing to the great reduction of current supplied to this line by the Elyria station, the remaining feeders would be ample to carry the load with much larger reserve capacity than exists under the present conditions with all the feeders in place. This feeder,

consisting of 8½ miles of 300 000 circular mil cable, supplies ample feeder copper for all of the negative return cables that will be required under the proposed system, so that no purchase of additional copper is contemplated.

2. INTERCONNECTION OF TRACKS

At the present time there is no connection between the tracks of the Cleveland, Southwestern & Columbus Railway to the Lake Shore Electric Railway in Elyria. These tracks approach quite closely to each other, particularly where they cross West Street and again at Mill Street, and they run very roughly parallel between those two points. Since the current flow in the two tracks in these parallel sections is in the opposite direction, it inevitably tends to set up large potential differences between the tracks, thus giving rise to heavy cross currents in the earth which may get onto the pipes and cause injury. It is proposed to interconnect the tracks electrically at West Street and on Mill Street. These interconnections will permit an interchange of current between the two tracks which will prevent the current from flowing in opposite directions in the two parallel sections, thus greatly reducing stray currents. It will also reduce the effective value of the current on both of the tracks, thus reducing to some extent the energy losses of both lines.

3. IMPORTANCE OF SELECTING PROPER TYPE OF RETURN SYSTEM

It has heretofore been generally considered by railway engineers that to maintain the very low voltage drops in the tracks that are necessary to reduce electrolysis to a substantially negligible amount would require so much copper in the negative return system that the cost would be prohibitive in most cases. This idea has become prevalent because the estimates usually made are based on the use of the ordinary type of uninsulated negative feeders which are connected in parallel with the tracks. With this system the feeders increase the conductivity of the tracks in proportion to the cross section of copper installed. Further, the drop of potential on the cables can not be greater than the drop on the tracks, since the two are connected electrically in parallel

throughout. In order to work copper cables economically it is necessary to use a current density of at least several hundred amperes per million circular mils, which means a voltage drop of several volts per 1000 feet in the cables. Experience has shown, however, that track gradients of this magnitude are altogether too high when viewed from the standpoint of safety to the pipes, so that if uninsulated feeders are installed, it is impossible to secure at the same time adequately low voltage conditions and economical use of the feeder cooper.

We concur in the view that, if the ordinary uninsulated type of feeder system be used, the cost of maintaining voltage drops in the tracks low enough to prevent material electrolysis on the pipes will be excessive. If the desired low-voltage conditions are to be maintained at a reasonable cost for copper it is necessary to adopt some type of return system whereby the drop in the tracks can be kept independent of the drop in the cables, so that the cables can be worked at the high-current densities which economy demands, while at the same time the potential differences in the tracks are kept very low. This result can readily be accomplished by the use of insulated negative feeders, and by adopting this construction any desired reduction in track voltages can be secured at a small fraction of the cost that would be required by the ordinary type of uninsulated feeders. Furthermore, this system, when properly installed, does not introduce any operating complications, and, as will appear later, in the present case no increase in energy losses in the negative return will be involved. The recommendations contained in the following report, therefore, contemplate the use of insulated feeders wherever negative feeders of any kind are necessary.

4. PRINCIPLES OF THE INSULATED NEGATIVE FEEDER SYSTEM

The principles upon which the insulated feeder system recommended for Elyria depends, together with a discussion of other methods of electrolysis mitigation included in the original report to the officials of Elyria, has been omitted from this published report because these discussions are now available in a more complete form in Technologic Paper No. 52, Methods of Electrolysis Mitigation.

~~Fig. 5~~

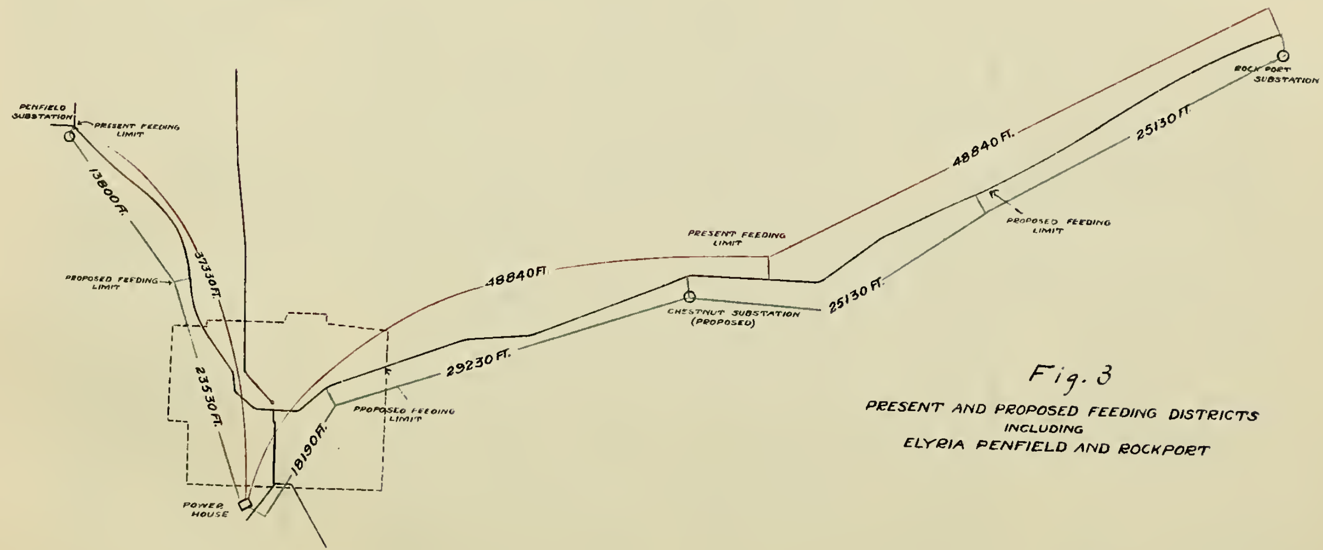


Fig. 3

PRESENT AND PROPOSED FEEDING DISTRICTS
INCLUDING
ELYRIA PENFIELD AND ROCKPORT

IV. REARRANGEMENT OF FEEDING SYSTEM

The present feeding system for the Elyria-Cleveland and Elyria-Penfield lines is shown in Fig. 3, the red lines indicating the present feeding limits. The present direct-current rated capacity of the Elyria station is 1500 kilowatts, of the Rockport station 600 kilowatts, and of the Penfield substation 500 kilowatts. It is recommended that arrangements be made for permitting the Penfield substation to feed one-half of the Penfield-Elyria line, preferably by increasing its capacity by at least 150 kilowatts, or more if the company so desires. The Elyria-Cleveland line is to be taken care of by an additional substation of 300 kilowatts capacity located at Chestnut. Under this plan the feeding distances of the different stations will be as shown in Fig. 3 by the green lines. In this case it will be noted that both the Elyria and Penfield stations each feed one-half of the track section between Elyria passenger station on Court Street and the Penfield substation. The proposed substation at Chestnut feeds halfway between Chestnut and Rockport and considerably more than halfway between Chestnut and Elyria power house. This latter is because electrolysis mitigation in Elyria makes it much more economical to feed as far as practicable from the east, so as to reduce the amount of current that is to be returned to the Elyria power station through the heart of the city of Elyria, where the underground utilities are highly developed. All calculations are based on the assumption that the feeders and bus-bar voltages at the different stations are so adjusted that on the average the region about Gulf Street and Cleveland Street will constitute approximately the neutral zone between the Elyria and Chestnut stations. An examination of the figures showing the distances of feed on either side of the Chestnut station shows that it is designed to supply current to about 59 300 feet of track. As will be shown later, the average current originating in this line corresponds to about 5.38 amperes per 1000 feet, so that this station will be called on to supply an average of about 318 amperes. This corresponds to a maximum demand of approximately 700 amperes, or 420 kilowatts at 600 volts. A station of 300 kilowatts capacity would therefore be ample to take care of present conditions, and

this size has been used as a basis for the figures given later in this report. If it is deemed desirable by the management to install a larger machine at this time to take care of future growth of traffic, this might well be done, but any excess cost on that account should be charged to future growth, and consequently should not be considered in the present problem of electrolysis mitigation.

The power supply to the proposed Chestnut substation would probably be over a high-tension transmission line from the Rockport substation. The cost estimate for this line given later in this report is based on 13 000 volt construction, but this estimate will not be materially affected by any variation in the voltage adopted within the limits imposed by good practice for this kind of transmission. A single three-phase line is planned, since absolute continuity of service is not demanded. If the line should be temporarily put out of service, as it might be on rare occasions, the cars could still be run nearly as well as they are at the present time, so that the slight disturbance that would result would hardly justify the expense of a duplicate transmission line. No. 4 wire is specified in the estimates for insuring ample mechanical strength, although this is much larger than is needed to carry the small load of 300 to 400 kilowatts which will be demanded of this line. Additional specifications for this line are given later in connection with the cost estimates.

V. INTERCONNECTION OF TRACKS OF THE TWO ELECTRIC RAILWAY SYSTEMS

There are operating in Elyria two separate electric railway lines which do not intersect, but which approach quite close to each other at certain points. This is shown in Fig. 3, which gives the track layout for Elyria and vicinity. The power houses supplying these two lines are located so that the current in the tracks in those lines which are approximately parallel flow in opposite directions, and this condition is one which greatly increases the danger from electrolysis. This is illustrated by Fig. 4, in which the black arrows indicate the direction of current flow in the different tracks. It will be obvious that since the fall of potential in the two tracks is in opposite directions, it will be impossible

~~24~~

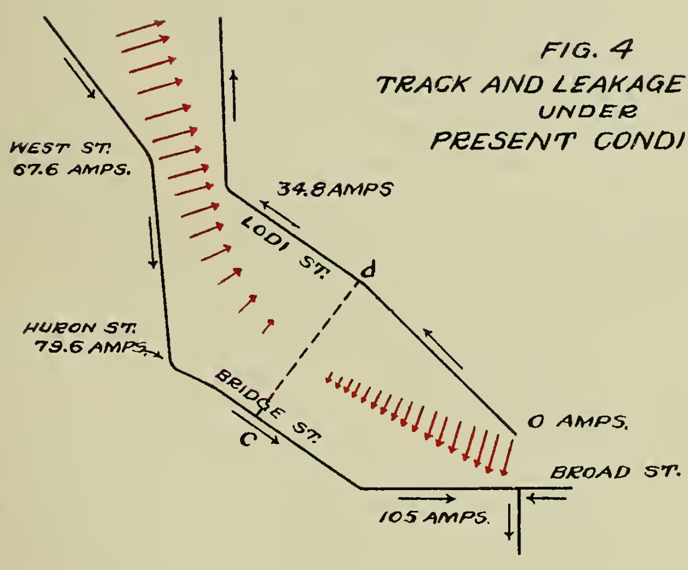


FIG. 4
TRACK AND LEAKAGE CURRENT
UNDER
PRESENT CONDITIONS

No. 205
Ed. 1-13-15—1,000,000

for adjacent points of the two lines to be at the same potential, and hence cross currents will be set up in the earth between the two lines, and these may get into the pipe systems and ultimately cause injury. If, for example, we consider two points on the two lines, such as *c* and *d*, which may at any particular time be at the same potential, there would be no tendency for current to flow directly across between these two points. If we proceed southeast from the point *d*, however, the potential of the tracks rises because the current flow is toward the north, and the farther south we go the higher the potential of the tracks becomes till the end of the line is reached. Going southeast from the point *c*, however, the potential of the Cleveland, Southwestern & Columbus Railway tracks is falling, since we are going in the direction of current flow. It is evident, therefore, that the farther we go in this direction the greater will be the potential difference between the tracks, those of the Lake Shore Electric Railway being at the higher potential, and hence current tends to flow from this line across through the earth to the tracks of the Cleveland, Southwestern & Columbus Railway on Broad Street. To the north of the points *c* and *d* a similar condition evidently exists, except that the potential conditions are reversed, and the leakage current tends to flow from the Cleveland, Southwestern & Columbus Railway tracks to those of the Lake Shore Electric Railway. The red arrows show the general trend of this leakage current, the arrow being longer where the leakage current is greater. If, now, the two lines be tied together electrically at suitable points where they approach each other, a very different condition exists. In this case the most suitable points for tying the tracks together are on Mill Street and on West Street, where the tracks approach within a few hundred feet of each other. Assuming, for purposes of illustration, that the tracks are tied closely together at these points and that no appreciable potential difference can exist at the points of tie, it will be evident that the potential drop in the two parallel sections must be the same and in the same direction, and hence the current can not flow in opposite directions as before. Since the potential gradient is now in the same direction and of substantially the same value, any two points such as *A* and *B*, Fig. 5, substantially opposite each other, must be at prac-

tically the same potential, and hence the tendency to set up cross currents between the two tracks through the earth is almost entirely eliminated. Further, since the current in the two lines tends to flow in opposite directions between the points where the tracks are tied together, the resultant current in the tracks will be the difference between the individual track current, and hence smaller than before. This further reduces the differences of potential between the points *aa* and *bb*, with consequent improvement in electrolysis conditions. It also results in reducing the potential drops in the negative return of both railway lines, with corresponding reduction in the negative losses. The precise dis-

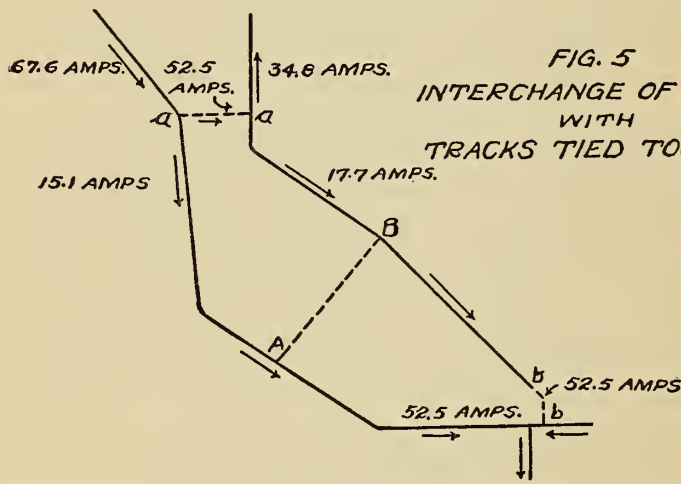


FIG. 5
INTERCHANGE OF CURRENT WITH TRACKS TIED TOGETHER

tribution of current flow on the tracks thus tied together is shown in detail below for average conditions of traffic.

The originating current on Lake Avenue is 7.6 amperes per 1000 feet. The distance from the feeding limit to the corporation line is 4400 feet. Hence the current in this section is 33.4 amperes.

Between the corporation line and West Street, where the tracks of the two systems are tied together, the distance is 4500 feet, and the current originating here is $4.5 \times 7.6 = 34.2$ amperes, so that the total accumulated current up to West Street is $33.4 + 34.2 = 67.6$ amperes. Since the tracks are tied together on West Street and again at Mill Street, we must now determine the distribution of current in this interconnected section in order

to determine whether the voltage drops therein will reach unsafe values. It will be evident that the lowest average potential gradients will be obtained if the current is divided approximately equally between the two parallel lines, provided both tracks have the same resistance per unit length as is here assumed. As already pointed out, the average current per 1000 feet originating in the tracks of this section of the Cleveland, Southwestern & Columbus Railway is 7.6 amperes, and an examination of the car schedule of the Lake Shore Electric Railway indicates a current

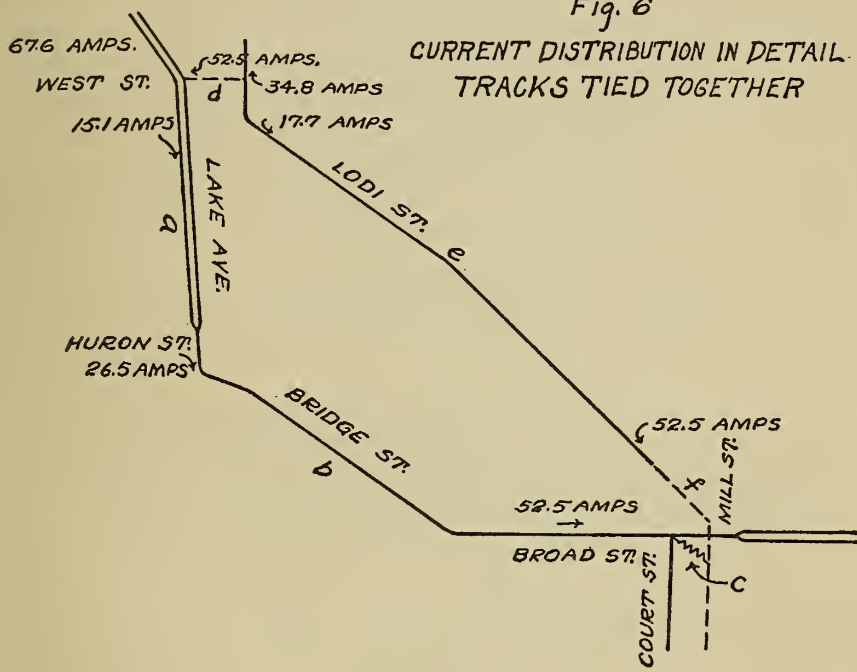


Fig. 6

CURRENT DISTRIBUTION IN DETAIL
TRACKS TIED TOGETHER

of about 10.1 amperes per 1000 feet of track. The length of the section on Lodi Street between West and Mill Streets is 3440 feet, and the current originating in this section is 34.8 amperes. Since we have a total of 105 amperes in the Penfield section that must be delivered to the track at Broad and Court Streets, if the maximum current density in the two branch lines is to be the same, we must have 52.5 amperes brought to Broad and Court Streets by each line. This means that 52.5 amperes must flow across the tie on West Street, and at any point on Lodi Street the resultant

current will be the difference between this 52.5 amperes and the current that would flow in the track at that point, provided there were no interconnection of the lines. The current distribution can best be seen by reference to Fig. 6. Of the 67.6 amperes in the Lake Avenue tracks at West Street, 52.5 amperes are to be taken over the West Street tie, the remaining 15.1 amperes remaining on the Lake Avenue tracks as shown. Between West Street and the end of the double tracks on Huron Street the distance is 1500 feet, so that the current originating here is $7.6 \times 1.5 = 11.4$ amperes. The total current in the tracks at Huron Street is therefore $15.1 + 11.4 = 26.5$ amperes. Between Huron Street and Court Street the distance is 3400 feet, and the current originating here is $7.6 \times 3.4 = 26$ amperes, approximately. On Lodi Street and West Street there is an interchange of current between the two systems, part of the current, amounting to 34.8 amperes, coming across on the West Street tie turning north, and the difference, or 17.7 amperes, going south. Between here and Mill Street 34.8 amperes originate, as above stated, so that the total current in the tracks at Lodi and Mill Streets is $17.7 + 34.8 = 52.5$ amperes, which is just the same as in the tracks on Broad Street, as shown above.

At Broad and Court Streets there is an insulated negative feeder which takes off a portion of the current accumulating at that point from three directions, viz, West Broad Street, Mill Street, and East Broad Street, the amount taken off being such that the potential gradient in the tracks on Court Street will not exceed the average limit of 0.3 volt per 1000 feet, as explained later. It now remains to show how the system of ties and feeders can be installed so as to give the current distribution above assumed. Referring to Fig. 6, *a*, *b*, *c*, *d*, *e*, and *f* represent the different portions of the circuit, which have to be considered separately because of their having different resistances per unit length or carrying different currents. *a* is the double-track section between West Street and Huron Street. Its length is 1500 feet and its resistance $1.5 \times 0.003 = 0.0045$ ohm. *b* is the single-track section between Huron and Court Streets. *d* is the tie on West Street, which consists of a 900 000 circular mil cable, 430 feet long, having a resistance of 0.0054 ohm. *e* is the track on Lodi Street, with

resistance of 0.0206 ohm, and *f* the tie on Mill Street. This consists of a 600 000 circular mil cable 420 feet long and having a resistance of 0.0079 ohm. *c* is a small resistance tap which it has been found necessary to install between the tracks at Broad and Court Streets in order to secure the desired current distribution with reasonable economy of copper in the ties on West and Mill Streets.

The drop of potential along the path *a*, *b*, *c* must be equal to that along the parallel path *d*, *e*, *f*, hence we have the relation $E_a + E_b + E_c = E_d + E_e + E_f$. With the currents distributed as above assumed, it is easily seen from Fig. 6 and the foregoing data on the resistance of the different portions of the circuit that the terms of equation (1) have the following values:

$$E_a = I_a R_a = \frac{15.1 + 27.5}{2} \times 0.0045 = 0.10 \text{ volt}$$

$$E_b = I_b R_b = \frac{26.5 + 52.5}{2} \times 0.0204 = 0.80 \text{ volt}$$

$$E_d = I_d R_d = 52.5 \times 0.0054 = 0.28 \text{ volt}$$

$$E_e = I_e R_e = \frac{17.7 + 52.5}{2} \times 0.0206 = 0.72$$

$$E_f = I_f R_f = 52.5 \times 0.0079 = 0.41.$$

Substituting these values in equation (1) we can calculate the drop of potential which we must allow on the resistance tap *C* in order that the current distribution shall automatically be as assumed. We have

$$E_c = 0.28 + 0.72 + 0.41 - 0.80 - 10 = 0.51 \text{ volt}$$

The drop on the resistance *C* must therefore be 0.51 volt. The resistance of this tap will be determined later, when we come to calculate the insulated negative feeder system to be installed.

VI. DETAILED CALCULATION OF INSULATED NEGATIVE FEEDER SYSTEM

1. BASIS OF CALCULATION

(*a*) *Limiting Gradients.*—All of the feeder calculations which follow are based on a limiting 24-hour average potential gradient in the tracks of 0.3 volt per 1000 feet, which under the load con-

ditions existing in the Elyria lines corresponds to a maximum value for any 15-minute period of about 0.75 volt per 1000 feet. Since the current is actually delivered to the tracks at a few points continually moving to and fro along the lines the track gradient will, of course, vary considerably and reach values for short periods very much greater than the limit here fixed; but it is the average figure that is most important, particularly when the variations in voltage repeat themselves at comparatively short intervals of an hour or less. Further, since the average gradient can be predetermined with much greater accuracy than any short-time value, the 24-hour average voltage gives a better basis for calculations. The calculations are based on the assumption that all rail joints are in good condition. Since the tracks are laid with 73-pound rails, the resistance is 0.006 ohm per 1000 feet of single track, and 0.003 ohm per 1000 feet of double track. The average voltage limit of 0.3 volt per 1000 feet and the track resistances, as stated, make the limiting average current in the single track 50 amperes and in the double track 100 amperes.

(*b*) *Current Density in Copper Cables.*—In determining the size of copper cables two considerations have been kept in mind—first, to use approximately that cross section of copper which would give the most economical use of the copper, all things considered. However, since, as already stated, the removal of the positive feeder now extending from the Elyria power house to Ridgeville will make available enough 300 000 circular mil cable to supply all of the copper required for the negative feeder system, it is found most economical to use this size throughout, several cables being used where a larger cross section than 300 000 circular mil is necessary. We have, therefore, determined approximately the current density in the cables which would give the greatest operating economy, and then have used the nearest size to this that could be had in a 300 000 cable or a multiple of this size. Second, because of the fact that high-current density in the cables leads to increased loss of power in the resistance taps at the power house and other points on the line, it will be most economical to work the cables at a somewhat lower-current density than would be the case if we were considering only the energy loss in the cable itself. Careful calculations have shown

that a current density of approximately 150 amperes per 1 000 000 circular mils (average for the 24-hour period) would be most economical under the conditions that will exist in this installation. We have, therefore, endeavored to approximate this current density as closely as practicable.

(*c*) *Resistance of Copper Cables.*—The resistance of all copper cables is based on the assumption that the resistance per 1000 feet of a 1 000 000 circular mil cable is 0.0113 ohm. This is the correct value at a temperature of about 37° C, which is a fair figure for the all-year average when we take into account the heating effect of the current in the cables.

2. DETAILS OF FEEDER SYSTEM

We shall now proceed to calculate in detail the insulated negative feeder system required to maintain the potential gradients in Elyria within the limits prescribed above, namely, 0.3 volt per 1000 feet, average for the 24 hours. It has already been shown under the discussion of interconnection of tracks that if the tracks of the Cleveland, Southwestern & Columbus Railway and the Lake Shore Electric Railway are connected on West Street and on Mill Street, the interchange of current between the tracks will be sufficient to keep the potential gradients below 0.3 volt, which is set as the limit, in all portions of the track between the corporation line on Lake Avenue and Court Street and Broad Street, so that it will not be necessary to run any negative feeders west of Court Street.

Considering, now, the line running east on Broad Street and East Bridge Street, we have already assumed that Gulf Street constitutes on the average the dividing line for the feeding distances between the Elyria station and the proposed Chestnut substation. The current distribution on the tracks of this branch is taken at 5.38 amperes per 1000 feet. This is determined by taking the total average load on all of the feeders supplying the Cleveland branch from the Elyria power house and dividing this by one-half the distance between the Elyria power house and the Rockport substation. The average load on this line, as determined by recording meter charts taken on positive feeders at the Elyria power house, is 262.9 amperes. The distance between the

Elyria power house and the point halfway to Rockport is 48 840 feet, so that the average current originating in the tracks is 5.38 amperes per 1000 feet of track. Between Gulf Street and the beginning of the double track at East Broad and East Bridge Streets the distance is 2400 feet, so that the total current originating in this section is $5.38 \times 2.4 = 12.9$ amperes, which is far below the limiting capacity of 50 amperes of the single track. On the double track between East Bridge and Washington Streets the distance is 1680 feet, and the current originating here is $1.68 \times 5.38 = 9.1$ amperes. In the next section between Washington Street and Court Street the distance is 380 feet, and the current originating here is $0.38 \times 5.38 = 2$ amperes. The total current then originating on the tracks east of Court Street that can be returned to the Elyria power house is $12.9 + 9.1 + 2 = 24$ amperes.

In a preceding section, under "Interconnection of tracks," we have shown that the current coming from the west on Broad Street at this point is 52.5 amperes, so that the total current on the tracks at Broad and Court Streets is $52.5 + 24 = 76.5$ amperes. Since the track south of here on Court Street and Middle Avenue is single track, it can not carry this current without exceeding the 0.3-volt limit, so a portion must be taken off here, and the amount taken off must be sufficient to keep the current below the 50-ampere limit down to the next succeeding tap, which has been located at the turnout between Eighth and Ninth Streets, hereinafter called Eight-and-a-half Street. The distance from Broad Street to Eight-and-a-half Street is 3240 feet. The current originating per 1000 feet in this track is greater than on the East Broad Street line because of the fact that the Grafton cars run on Middle Avenue. An examination of the car schedule shows that the average current per 1000 feet on the Grafton line is about 2.52 amperes. Adding this to the 5.38 amperes per 1000 feet for the Cleveland branch gives a total of 7.9 amperes per 1000 feet originating in the tracks between Broad Street and Sixteenth Street. Consequently the current originating in the section between Broad and Eight-and-a-half Streets is $3.24 \times 7.9 = 25.6$ amperes. Adding this to the 76.5 amperes which comes from Broad Street gives a total of 102.1 amperes that would be on the tracks at Eight-and-a-half Street if none were taken off at Broad Street. We shall

therefore plan to take off about 50 amperes at Broad Street, which would keep the current in the tracks at Eight-and-a-half Street at just about the prescribed limit. This 50 amperes taken off at Broad Street flows through the resistance tap between the feeder and the tracks at Broad Street as described in the previous chapter under "Interconnection of tracks."

In that chapter it was found that the potential drop on this tap would have to be 0.5 volt in order to give a proper interchange of current between the tracks of the two railway systems. The resistance of this tap will therefore be $0.5 \div 50 = 0.01$ ohm. It was also shown in the chapter just referred to that the current already on the cable coming from the Lodi Street tracks via Mill Street was 52.5 amperes, and adding this to the 50 amperes taken off at Broad Street makes a total of 102.5 amperes on the cable between Broad and Eight-and-a-half Streets. To carry this current we will use three 300 000 circular mil cables. The resistance of this between Broad Street and Eight-and-a-half Street is 0.0125 ohm per 1000 feet, and since the length is 3240 feet the total resistance is $3.24 \times 0.0125 = 0.0405$ ohm, and the drop of potential on the cable in this section is $0.0405 \times 102.5 = 4.15$ volts. Adding this to the drop on the tap at Broad Street, which was found above to be 0.5 volt, we get 4.65 volts as the potential difference between the tracks at Broad and Court Streets and the cable at Eight-and-a-half Street. The current remaining on the tracks just south of Broad Street is $76.5 - 50 = 26.5$ amperes, and since the current originating in this section was shown to be 25.6 amperes, the total current on the tracks at Eight-and-a-half Street is 52.1 amperes while the mean is 39.3 amperes. Since the resistance of this single track is 0.006 ohm per 1000 feet, the drop of potential on the track between Broad Street and Eight-and-a-half Street is $39.3 \times 0.006 \times 3.24 = 0.764$ volt. The drop of potential on the resistance tap at Eight-and-a-half Street will therefore be $4.65 - 0.76 = 3.89$ volts.

The next tap south of here between the cable and the tracks will be placed at the corporation line on Sixteenth Street. The distance between Eight-and-a-half and Sixteenth Streets is 2670 feet, so that the current originating in this section is $2.67 \times 7.9 =$ 21.1 amperes. Adding this to the 52.1 amperes remaining on the

tracks at Eight-and-a-half Street would give a total of 73.2 amperes, so that in order to keep down to the 50-ampere limit it will be necessary to take off approximately 25 amperes through the tap at Eight-and-a-half Street. The drop on this tap has just been found to be 3.89 volts, so that its resistance will be $3.89 \div 25 = 0.155$ ohm. The current left on the tracks south of Eight-and-a-half Street is then $52.1 - 25 = 27.1$ amperes, and the current on the tracks at Sixteenth Street is $27.1 + 21.1 = 48.2$ amperes. The mean current in this section is, therefore, 37.6 amperes, and the drop of potential on the tracks between Eight-and-a-half and Sixteenth Streets is $37.6 \times 0.006 \times 2.67 = 0.6$ volt. The current on the feeder south of Eight-and-a-half Street is $102.5 + 25 = 127.5$ amperes. The same size feeder, namely, 900 000 circular mils, is sufficient to carry this current, so that the three 300 000 circular mil cables will be continued to Sixteenth Street. The drop of potential on this section is, therefore, $127.5 \times 0.0125 \times 2.67 = 4.25$ volts. Adding this to the drop on the tap on Eight-and-a-half Street, which is 3.89 volts, and subtracting the track drop in this section, which has been shown to be 0.6 volt, we find that the drop on the tap at Sixteenth Street is $4.25 + 3.89 - 0.6 = 7.54$ volts.

The total current supplied by the Grafton line is taken at 100 amperes average, and on the basis of uniform average distribution along the line 14.9 amperes of this would originate between Broad and Sixteenth Streets, leaving 85.1 amperes originating south of Sixteenth Street and Middle Avenue. As shown above, the current coming from the north on the tracks at Sixteenth Street is 48.2 amperes, and adding this to the 85.2 amperes coming from the Grafton line we get a total of 133.3 amperes accumulated on the tracks at Sixteenth Street and Middle Avenue. Between this point and the tracks near the power house, a distance of 2920 feet, there originates $2.92 \times 5.38 = 15.7$ amperes, giving a total of 149 amperes which would accumulate on the tracks up to the power house. In order not to exceed the 50-ampere limit, therefore, it will be necessary to take off about 100 amperes of current through a tap at Sixteenth Street, and since the drop on this tap has been shown to be 7.54 volts, the resistance of this tap will be $7.54 \div 100 = 0.0754$ ohm. The current remaining on

the track south of Sixteenth Street will, therefore, be $133.3 - 100 = 33.3$ amperes, and the current on the tracks at the power house will be $33.3 + 15.7 = 49$ amperes. The mean current in this section is, therefore, 41.1 amperes, and the drop of potential on the tracks is $41.1 \times 0.006 \times 2.92 = 0.7$ volt.

The cable south of Sixteenth Street will be carrying $127.5 + 100$ amperes $= 227.5$ amperes. This will call for about 1 800 000 circular mils, so that it is contemplated to use six 300 000 circular mil cables between Sixteenth Street and the power house. The length of this section, including the distance between the power house and the tracks, which is approximately 900 feet, is 3820 feet, and the resistance of the 1 800 000 circular mils cable is 0.0063 ohm per 1000 feet, so that the drop of potential on the cable between Sixteenth Street and the bus bar is $227.5 \times 0.0063 \times 3.82 = 5.47$ volts. Adding this to the drop on the Sixteenth Street tap, found to be 7.54 volts, and subtracting the track drop between Sixteenth Street and the point on the tracks opposite the power house, which was found to be 0.7 volt, we get 12.3 volts as the drop of potential on the resistance tap that must be inserted between the tracks and the negative bus bar at the power house.

In the above calculations we have assumed a certain current distribution in the tracks and feeders at various points and have then calculated the size of the cables and the resistances of the resistance taps necessary to produce the assumed current distribution. If the cables and resistance taps are installed as above calculated, it is obvious that the system will automatically give the current distribution as originally assumed. Summarizing the results of the above calculations, we find that in order to maintain the potential gradients in the tracks within the city of Elyria between the corporation line at Sixteenth Street and the power house everywhere at a value not exceeding 0.3 volt per 1000 feet average for 24 hours, and at the same time secure approximately maximum economy in the installation, we must run a feeder between the negative bus of the Elyria power station and the tracks of the Lake Shore Electric Railway at Lodi and Mill Streets. This feeder will be connected to the tracks of the Cleveland, Southwestern & Columbus Railway through resistance taps at Sixteenth Street and at Eight-and-a-half Street and at Broad and

Court Streets, and there will also be a resistance tap between the negative bus and the tracks at the power house. The resistance tap at Broad and Court Streets has a resistance of 0.01 ohm, that at Eight-and-a-half Street 0.155 ohm, and that at Sixteenth Street 0.0754 ohm.

The tap at the power house has already been shown to have a drop of potential of 12.3 volts. To get the resistance of this tap, we must consider not only the 49 amperes coming from the east on the tracks at this point, but also the current from the Oberlin branch. This latter has an average value of 269 amperes, so that the total current on the power-house tap is 269 + 49 = 318 amperes, and the resistance of the power-house tap is 12.33 ÷ 318 = 0.038 ohm. It will also be seen in summarizing the above figures that the area of the negative feeders between the power house and Sixteenth Street is 1 800 000 circular mils, between Sixteenth and Broad Streets 900 000 circular mils, and between Broad Street and Lodi Street 600 000 circular mils. The total amount of copper expressed in 1000 feet of 300 000 circular mil cable is shown in Table 3. From this it will be seen that the total copper required is 42 780 feet of 300 000 circular mil cable. The removal of the present 300 000 circular mil positive feeder between the power house and Ridgeville makes available 44 880 feet of 300 000 circular mil cable. This is more than sufficient to supply all of the cable needed for the proposed negative feeder system, so that no new copper will have to be purchased. A negative feeder system, as calculated above, is shown in Fig. 7.

TABLE 3

Copper Required in Insulated Negative Feeder System

Location	Area	Length	Equivalent length of a 300 000 circular mil cable
	Circular mils	Feet	Thousand feet
On Mill Street between Lodi Street and Broad Street	600 000	420	0.84
From Broad Street to Sixteenth Street	900 000	5910	17.73
From Sixteenth Street to negative bus	1 800 000	3820	22.92
On West Street between Lake Avenue and Tyler Street	900 000	430	1.29
Total			42.78

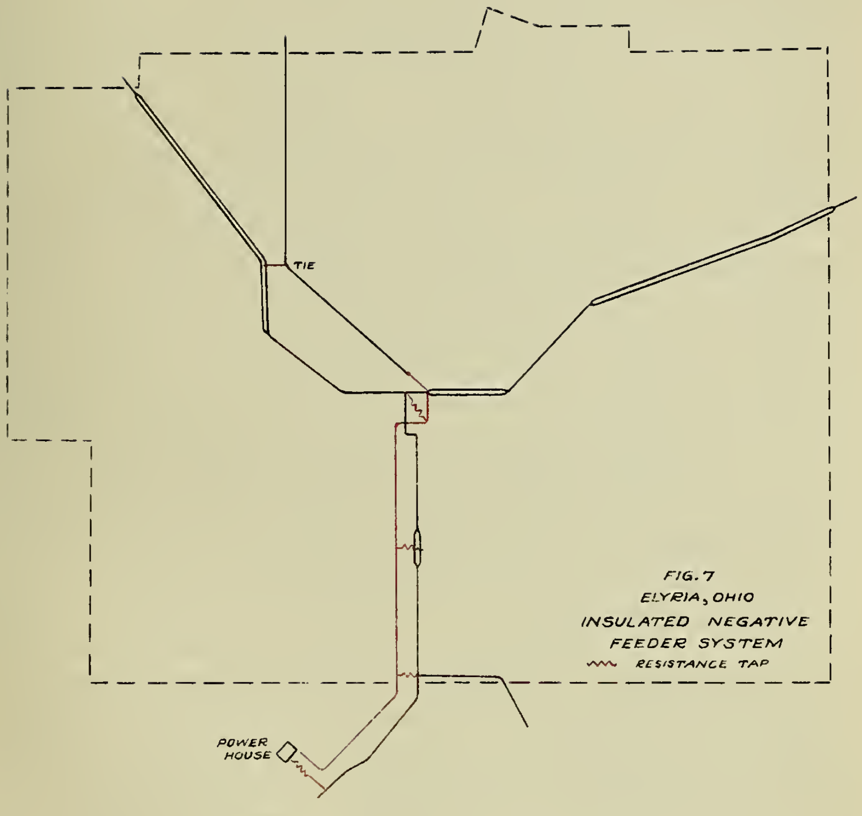


FIG. 7
ELYRIA, OHIO
INSULATED NEGATIVE
FEEDER SYSTEM

VII. OVER-ALL POTENTIALS UNDER PROPOSED PLAN

We are now in a position to calculate the over-all potential differences that will exist under the proposed method of mitigation. Beginning first with the tracks at the corporation line on Lake Avenue, we have already seen that under the proposed plan the Elyria station feeds northward a distance of 4400 feet beyond the city line. The current originating here is 7.6 amperes per 1000 feet. The total current in the tracks at the corporation line would be $7.6 \times 4.4 = 33.4$ amperes. Between this point and West Street 34.2 amperes originate, making the total current at West Street 67.6 amperes. The mean current between West Street and the corporation line is, therefore, 50.5 amperes, hence the average drop of potential on the tracks between the corporation line and West Street is $4.5 \times 0.003 \times 50.5 = 0.68$ volt. It has already been shown, in a previous chapter in connection with the calculation showing the effect of interconnecting the tracks of the two railway lines, that the drop of potential on the tracks between West Street and Court and Broad Streets is 0.9 volt. It has also been shown, in a preceding chapter giving the calculations on the negative return feeder system, that the drop of potential on the tracks between Broad and Eight-and-a-half Streets is 0.76 volt, and between Eight-and-a-half and Sixteenth Streets 0.6 volt. Summing up these component drops we find that the total over-all potential between the corporation line on Lake Avenue and the corporation line on Sixteenth Street is $0.68 + 0.90 + 0.76 + 0.60 = 2.94$ volts average for 24 hours. This corresponds to a 15-minute maximum voltage of approximately 7.4 volts.

To get the drop of potential between the corporation line on Sixteenth Street and the intersection of Gulf and Cleveland Streets, we add to the drop on Middle Avenue, which has been shown to be 1.36 volts, the drop on the tracks between Broad and Court Streets and Gulf Street. In the section between Washington and Court Streets we have a single track 380 feet long carrying an average current of 23 amperes, so that the drop in this section is $0.38 \times 0.006 \times 23 = 0.05$ volt. In the next section between Washington Street and the intersection of East Bridge and East Broad Street the distance is 1680 feet. The current in the tracks at the

east end of this point has been shown to be 12.9 amperes, and at Washington Street it is 22 amperes, so that the mean current is 17.45 amperes. The drop in this section is therefore $1.68 \times 0.003 \times 17.4 = 0.09$ volt. Between the intersection of Broad and East Bridge Streets and Gulf Street the distance is 2400 feet, and the mean current is $12.9 \div 2 = 6.45$ amperes. The track here is single, so that the drop would be $2.4 \times 0.006 \times 6.45 = 0.09$ volt. The total drop between Gulf and Cleveland Streets and Court and Broad Streets is therefore 0.23 volt, and adding this to the drop between Broad and Sixteenth Streets, namely, 1.36 volts, we get a total of 1.59 volts as the average over-all potential between Gulf Street and Sixteenth Street, which corresponds to a 15-minute maximum value of about 4 volts. Between Gulf Street and the corporation line at Abbey Road the gradient is toward the east, so that the drop of potential on this section must be substracted from the potential difference between Gulf and Sixteenth Streets in order to get the over-all potential between Abbey Road and Sixteenth Street. In this section the track is double and the distance 4900 feet. The average current in this section is 18.6 amperes, so that the drop of potential is $4.9 \times 0.003 \times 18.6 = 0.27$ volt. Substracting this from 1.59 volts, we get 1.32 volts as the over-all potential between the corporation line at Abbey Road and the corporation line at Middle Avenue and Sixteenth Street. Similarly, to get the potential difference between the corporation line at Abbey Road and the corporation line at Lake Avenue, we have, summing up the component drops as above determined with due regard to their direction, $0.68 + 0.90 - 0.23 + 0.27 = 1.62$ volts. The other over-all potential differences are summed up from these components in the same way.

Comparing these over-all potential drops with those which the data presented in Table 1 show to exist under present conditions, we get the figures shown in Table 4. From this it will be seen that under present conditions the average over-all potential between the corporation line at Lake Avenue and at Sixteenth Street and Middle Avenue is 15.8 volts, compared to an estimated value of 2.94 under the proposed plan, which shows a reduction in the ratio of 5.4 to 1. Table 1 also shows that the average potential difference between the corporation line at Abbey Road

and Middle Avenue and Sixteenth Street is 19.7 volts, as compared with 1.32 under the proposed plan, which shows a reduction in the ratio of about 15 to 1. It will thus be evident that a tendency for leakage current to stray off the tracks into the earth will be reduced to a small fraction of the value that exists under present conditions, and electrolysis damage will be correspondingly reduced.

TABLE 4

Comparison of Present Over-all Potentials With the Calculated Values Under the Proposed Plan, 24-hour Average Values Given

Location	Value under present conditions	Value under proposed plan	Ratio
	Volts	Volts	
Lake Avenue and north corporation line to Middle Avenue and Sixteenth Street	15.8	2.94	5.3 to 1
Lake Avenue and corporation line to Court Street north of Third Street	9.1	1.58	5.7 to 1
Cleveland Street and Abbey Road to Lake Avenue and north corporation line	2.5	1.62	1.54 to 1
Cleveland Street and Abbey Road to Court Street north of Third Street	11.7	.04	292.0 to 1
Cleveland Street and Abbey Road to Middle Avenue and Sixteenth Street	19.7	1.32	15.0 to 1
Court Street north of Third Street to Middle Avenue and Sixteenth Street	7.1	1.36	5.2 to 1
Fremont and Lodi Streets / Court and Broad Streets	16.3	.09	181.0 to 1

VIII. ENERGY LOSSES

Before determining energy losses in the different portions of the positive feeder system and negative return we must determine the resistance constants of the various sections of the track. In order to determine the resistance of the positive feeder system extending from the Elyria power house in the direction of Rockport we can not consider the cables as connected in parallel with each other because of the manner in which they are connected to the trolley, the Elyria short feeder being connected in parallel with the trolley all the way from the power house to Abbey Road, but none of the other feeders being connected within that region. In order to calculate this distance, therefore, we lay out the feeder system showing the taps to the tracks, as shown in Fig. 8. Then,

by calculating separately the conductance of the individual branches, it is easy to calculate the resultant resistance between the power house and any particular point on the trolley wire. This resistance is shown as a function of the distance from the power house by the broken line at the bottom of Fig. 8. From this it will be seen that although the cross section of the positive feeder system is not by any means uniform, nevertheless the manner in which the positive feeders are connected to the trolley is such that the total resistance is approximately proportional to the distance from the power house, and this is so nearly true that this linear relationship is assumed in all of the energy calculations.

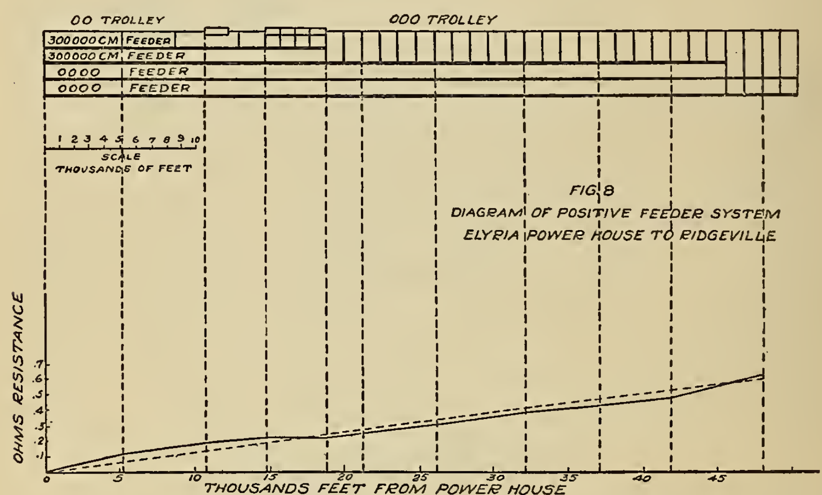


FIG. 8
DIAGRAM OF POSITIVE FEEDER SYSTEM
ELYRIA POWER HOUSE TO RIDGEVILLE

The straight dotted line in the figure shows the mean value of the resistance as a function of the distance from the power house, and by dividing any ordinate of this line by its corresponding distance from the power house we get the equivalent resistance of the positive feeder system in ohms per 1000 feet. This is found to be 0.013 ohm. Beyond the middle point between Elyria and Rockport we have two No. 0000 feeders in parallel with one No. 000 trolley, which gives a resistance of 0.019 ohm per 1000 feet, figuring the copper at an average temperature of 37° C. On the other sections of line the resistance of the positive feeder is easily determined from the cross section of the

feeder and the trolley, since the two are connected in parallel throughout. On the Penfield branch between the corporation line and Penfield substation we have one No. 000 trolley in parallel with a 500 000 circular mil feeder, which gives a resistance of 0.017 ohm per 1000 feet. Between the corporation line and Huron Street we have two No. 00 trolleys in parallel with one 500 000 circular mil cable, which gives a resistance of 0.015 ohm per 1000 feet. Between Huron Street and Court Street we have only one No. 00 trolley having a resistance of 0.085 ohm per 1000 feet. From Huron Street to the power house we have one 500 000 circular mil cable having a resistance of 0.0226 ohm per 1000 feet. The resistance of the single track is taken throughout as equal to 0.006 ohm per 1000 feet, and double track 0.003 ohm per 1000 feet. The resistance of all negative feeders, as well as the positive, is readily figured from the cross section on the basis that a 1 000 000 circular mil cable has a resistance of 0.0113 ohm per 1000 feet. For convenience in reference all of these resistance constants are shown in Tables 5 and 6 along with the power losses.

The calculation of the energy losses in any section of track can be very simply carried out by the use of a general formula. This formula can be derived as follows:

TABLE 5

Present Power Losses

1. POSITIVE LOSSES

Location	Description	r	L	I_1	I_2	P_2
Rockport halfway to Elyria	One No. 000+two No. 0000	0.019	48.84	0	262.5	30.50
Broad and Court Streets to eastern feeding limit.	Equivalent to a feeder having a resistance of 0.013 ohm per 1000 feet. (See Fig. 8.)	.013	40.03	0	215.0	11.52
Broad and Court Streets to Sixteenth Street.		.013	5.91	215.0	46.7	6.31
Sixteenth Street to tracks at power house.		.013	2.92	261.7	15.7	3.97
Track to negative bus		.013	.90	277.4	0	1.30
Penfield to corporation line	One No. 000+one 500 000 cm.	.017	18.20	0	138.4	2.82
Corporation line to Huron Street	Two No. 00+one 500 000 cm.	.015	6.00	138.4	45.6	3.38
Huron Street to Court Street	One No. 00+one 500 000 cm.	.085	3.40	0	26.0	.09
Huron Street to power house	One 500 000 cm	.0226	9.30	210.0	0	13.37
Total						73.26

TABLE 5—Continued

Present Power Losses—Continued

2. NEGATIVE LOSSES

Location	Description	r	L	I_1	I_2	P_2
Rockport to feeding limit	Single track	0.006	48.84	0	262.5	9.70
Abbey Road to feeding limit	...do	.006	30.63	0	164.0	2.38
Abbey Road to Gulf Street	Double track	.003	4.90	164.0	26.4	.68
Gulf Street to Broad and Bridge Streets.	Single track	.006	2.40	190.4	12.9	.81
Broad and Bridge Streets to Broad and Washington Streets.	Double track	.003	1.68	203.3	9.1	.32
Broad and Washington Streets to Broad and Court Streets.	Single track	.006	.38	212.4	2.0	.16
Penfield to corporation line	...do	.006	18.20	0	138.4	1.01
Corporation line to Huron Street.	Double track	.003	6.00	138.4	45.6	.72
Huron Street to Court Street	Single track	.006	3.40	184.0	26.0	1.14
Court and Broad Streets to Sixteenth Street.	...do	.006	5.91	424.4	46.7	10.26
Sixteenth Street to tracks near power house.	...do	.006	2.92	556.0	+15.7	8.02
Tracks to negative bus	3 000 000 cu. mils	.0037	.90	840.8	0	3.37
Total						38.57
Grand total						111.83

TABLE 6

Power Losses Under Proposed Plan

1. POSITIVE LOSSES

Location	Description	r	L	I_1	I_2	P_2
Rockport to feeding limit	One No. 000+two 0000	0.019	25.13	0	135.0	4.17
East feeding limit to Chestnut substation.	One No. 000+two 0000	.019	25.13	0	135.0	4.17
Chestnut substation to Abbey Road.	One No. 000+two 0000	.019	29.23	26.4	157.0	10.42
Chestnut substation to Abbey Road to Gulf Street.	Two No. 00+two No. 000+300 000 cm.	.0114	4.90	0	26.4	.01
Gulf Street to Bridge Street	One No. 00+two No. 0000+300 000 cm.	.013	2.40	0	12.9	00
Broad and Bridge Streets to Broad and Washington Streets.	Two No. 00+two No. 0000+300 000 cm.	.0114	11.68	12.9	9.1	00
Broad and Washington Streets to Broad and Court Streets.	One No. 00+two No. 0000+300 000 cm.	.013	.38	22.0	2.0	00
Penfield to southern feeding limit.	One No. 000+500 000 cm	.017	13.80	0	105.0	1.24

TABLE 6—Continued

Power Losses Under Proposed Plan—Continued

1. POSITIVE LOSSES—Continued

Location	Description	r	L	I_1	I_2	P_2
Northern feeding limit to corporation line.	One No. 000+500 000 cm....	0.017	4.40	0	33.4	0.04
Corporation line to Huron Street.	Two No. 00+500 000 cm.....	.015	6.00	33.4	45.6	.46
Huron Street to Court Street.....	One No. 00..................	.085	3.40	0	26.0	.09
Huron Street to power house.....	One 500 000 cm..............	.0226	19.30	105.0	0	3.35
Broad and Court Streets to Sixteenth Street.	One No. 00+two No. 0000+300 000 cm.	.013	5.91	24.0	46.7	.26
Sixteenth Street to tracks at power house.	One No. 00+two No. 0000+300 000 cm.	.013	2.92	70.7	15.7	.35
Tracks to negative bus..........	Two No. 0000+300 000 cm...	.013	.90	86.4	0	.16
Total....................	....	......	......	......	......	24.72

2. TRACK LOSSES

Location	Description	r	L	I_1	I_2	P_2
Rockport to feeding limit.........	Single track................	0.006	25.13	0	135.0	1.31
Feeding limit to Chestnut substation.	.....do....................	.006	25.13	0	135.0	1.31
Chestnut substation to Abbey Road.	.....do....................	.006	29.23	26.4	157.0	3.28
Abbey Road to Gulf Street.......	Double track................	.003	4.90	0	26.4	00
Gulf Street to Broad and East Bridge Streets.	Single track................	.006	2.40	0	12.9	00
East Bridge and Broad Streets to Washington and Broad Streets.	Double track................	.003	1.68	12.9	9.1	00
Washington and Broad Streets to Broad and Court Streets.	Single track................	.006	.38	22.0	0	00
Penfield to feeding limit.........	.....do....................	.006	13.80	0	105.0	.43
Feeding limit to corporation line..	.....do....................	.006	4.40	0	33.4	.02
Corporation line to West Street..	Double track................	.003	4.50	33.4	34.2	.06
West Street to Huron Street.....	.....do....................	.003	1.50	15.1	11.4	00
Huron Street to Court and Broad Streets.	Single track................	.006	3.40	26.5	26.0	.04
Broad and Court Streets to Eight-and-a-half Street.	.....do....................	.006	3.24	26.5	25.6	.04
Eight-and-a-half Street to Sixteenth Street.	.....do....................	.006	2.67	27.1	21.1	.03
Sixteenth Street to tracks at power house.	.....do....................	.006	2.92	33.2	15.8	.04
Total....................	....	......	......	......	......	6.56

TABLE 6—Continued

Power Losses Under Proposed Plan—Continued

3. NEGATIVE FEEDER LOSSES

Location	Description	r	L	I_1	I_2	P_2
On West Street between Lake Avenue and Lodi Street.	Three 300 000 cm	0.0125	0.43	52.5	0	0.01
On Mill Street between Lodi and Broad Streets.	Two 300 000 cm	.0190	.42	52.5	0	.03
On Middle Avenue between Broad and Eight-and-a-half Streets.	Three 300 000 cm	.0125	3.24	102.5	0	.60
On Middle Avenue between Eight-and-a-half and Sixteenth Streets.	Three 300 000 cm	.0125	2.67	127.5	0	.78
On Sixteenth Street between Middle Avenue and power house.	Six 300 000 cm	.0063	3.82	227.5	0	1.80
Total						3.22

4. RESISTANCE TAP LOSSES

	I	E					
At Broad and Court Streets	50	0.5					0.04
At Eight-and-a-half Street and Middle Avenue	25	3.89					.14
At Sixteenth Street and Middle Avenue	100	7.54					1.08
At power house	318	12.33					5.65
Total							6.91
Grand total							41.41

	Kw
Total power losses under present conditions	111.83
Total power losses under proposed plan	41.41
Total power saved by proposed system	70.42

The energy loss in any finite portion of a conductor is evidently equal to the I^2rdl where I is the current at any particular point, l on the line, and r is the resistance per unit length of the line. If the current originates in a uniform distribution along the line, as here assumed, this equation can be readily integrated, and gives the formula for power loss $p=r\ (I^2_1+I_1I_2+I^2_2\div 3)$ where I_1 is the

current entering the section in question from an outside source, and I_2 is the total current originating within the section under consideration, l is the length of the section, and r is the resistance per unit length. In all calculations which follow l is expressed in thousands of feet, and consequently r is in ohms per 1000 feet. Applying this formula to all of the different track and feeder sections and taking the resistance constants from the column headed r we get the energy loss for the different sections of track and feeders, as shown in the last columns in Tables 5 and 6. In applying this formula it should be borne in mind that since each term of the equation involves the second power of the current, the current to be used in substituting in the formula is what may be called the effective value of the current rather than the average value, the effective value being the square root of the mean square of the instantaneous values of current. Before using this formula, therefore, it is necessary, if accurate results are to be obtained, to determine the effective value of the current. This can readily be determined by plotting the load curves of the different feeders and by scaling off a large number of ordinates, squaring them, and taking the mean value of all and extracting the square root, which gives the square root of the average square, or the effective value of the current. A careful examination of the load charts of the Elyria feeder system shows that in all cases the effective value is very close to 20 per cent larger than the average value of current, consequently the second power of the effective current would be 1.44 multiplied by the second power of the average value. Since, however, the potential drops in the tracks, and also the danger from electrolysis is proportional to the average value rather than the effective value, all of the currents dealt with in the preceding portions of this report represent average values, and it is simpler to use these in substituting in the above formula. It is therefore necessary to multiply the results obtained by the above formula by the factor 1.44 in order to get the true average value of power loss. The working equation then becomes

$$p = 1.44\ r \left(I^2_1 + I_1 I_2 + \frac{I^2_2}{3} \right)$$

Summing up all of the losses in Table 5, we find that under present conditions the total losses in both positive and negative sides of the line in the district between Elyria and Penfield and between Elyria and Rockport is 111.8 kilowatts. From Table 6 we find that under the proposed plan the total losses, including also the losses in the negative feeders installed and the resistance taps, amount to 41.4 kilowatts. The reduction of power loss is therefore the difference between these two, or 70.4 kilowatts. This is the average 24-hour reduction in energy loss, which corresponds to a reduction of the peak-load losses of at least 200 kilowatts. The annual money value of this saving in power is discussed in detail in a later section of this report under the head of "Costs."

IX. POTENTIAL WIRES

It is very important in connection with any system of electrolysis mitigation to provide convenient means for determining at any time the voltage conditions that exist throughout the region where the underground utilities are appreciably developed and where they may be affected by stray currents. The best way of accomplishing this is to select some suitable central point, as at the power station or passenger station, or other available point in which a terminal board can be placed and run from this terminal board permanent insulated wires to the various points of the track system between which it may be desirable to measure potential differences. One of these wires should be run to the point of the system that is likely to be at lowest potential, and the others should be run to those portions of the line which may be expected to be at the highest potential within the city or area under consideration. In this way the maximum over-all potential drops in the negative return can readily be measured at the terminal board by connecting a voltmeter between the ends of the proper pair of wires. The installation of such potential wires is comparatively cheap and is very important for several reasons. In the first place, they permit any proper authorities to determine easily and quickly the over-all voltage conditions in the track network at any time, thus enabling them to keep a close watch on electrolysis conditions. They will also enable the railway

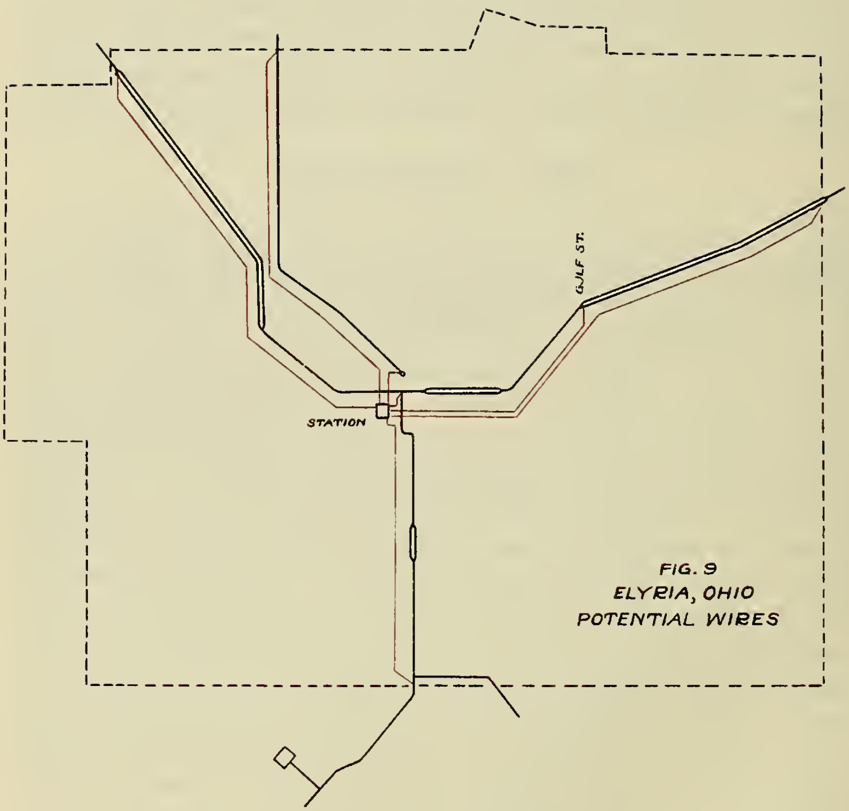


FIG. 9
ELYRIA, OHIO
POTENTIAL WIRES

company to determine in a general way the conditions of their tracks at any time by simply taking measurements on these lines at frequent intervals. Any sudden or abnormal change in the resistance of the unknown return system can at once be detected and repairs promptly made.

A great deal of the damage to underground structures by leakage current from railways is caused by the comparatively sudden development of high-resistance joints in the track, which give rise to very bad local electrolysis conditions, and if these potential wires are run to a number of points in the track network periodic tests will immediately show when any high resistance or open circuit in the track has developed, and thus permit the correction of the trouble before very serious damage to the underground structures has occurred. They are particularly important in connection with insulated negative return feeders, since they afford a means of keeping a line on the current distribution in the tracks, and therefore show whether anything has happened to the feeders or the resistance taps, such, for instance, as an open circuit or short circuit on a resistance tap, which might occasionally occur with serious results unless corrected within a short time. It should also be pointed out that when potential wires of this sort are installed they will enable the railway company to localize bad points in the track much more quickly and cheaply than could be done by ordinary testing methods without the use of such potential wires. In this way the potential wires become a source of economy which in most cases will more than pay for their installation. We would very strongly urge that potential wires of this sort be installed in all cases.

For Elyria we would recommend that potential wires of this character be run from a terminal board, preferably located in the passenger station on Court Street, since this is the most central point available and the installation of the wires will be cheaper if they are run to this point than if they are run from the power house. The potential wires recommended are shown in Fig. 9. Here it will be seen that one wire runs from the terminal board to the corporation line at Middle Avenue and Sixteenth Street, another to the corporation line on Lake Avenue, a third to the corporation line on Cleveland Street, and a fourth a short tap

running to the intersection of the tracks at Broad and Court Streets. It will also be seen that a wire is run from the terminal board to Gulf Street and Lake Avenue. The reason for this is that this is the neutral point between the feeding districts of the Elyria and Chestnut stations, so that this point will be generally at a higher potential than the corporation line on Cleveland Street. For this reason a higher over-all voltage would be found between Gulf Street and the other points than between the corporation line on Cleveland Street and the same points. This wire is also valuable in that it would permit the determination from time to time of the location of the neutral zone between the power-supply stations, and this would be useful in determining the voltages that are required at the bus bars of the stations in order that the correct distribution of current may be maintained. Fig. 9 also shows that a potential wire is run from this terminal board to the tracks on the Lake Shore Electric Railway at Lodi and Mill Streets and another to the point where this railway crosses the corporation line. This would, of course, be installed by the Lake Shore Electric Railway, and while it is not necessary that they should be run to the same terminal board as the other wires, it is very desirable that they should, in order that all of the over-all potential measurements may be taken at one point, thus greatly facilitating the taking of measurements.

These potential wires may be either copper, copper-clad steel, or galvanized iron, as preferred. The former are more expensive to install, but usually have the advantage of lower electrical resistance. Galvanized iron, however, if installed in sizes not smaller than No. 12, will have the advantage of relatively great mechanical strength, and its resistance in this case will not be a serious matter, and in any case it can usually be corrected with little difficulty. The use of galvanized-iron wire is much more economical than either copper or copper-clad steel, and at the same time is entirely adequate to meet the requirements of the present case, so this type of construction is to be preferred. The wire can be mounted on insulators on the pole line carrying the positive or negative feeders, or it can be suspended on porcelain insulators from the trolley span wires. This latter would probably generally be preferred, because it keeps the grounded wire

at a sufficient distance from the positive feeders. As a rule a single wire running to each point will be sufficient for all practical purposes. A pair of wires running to each point has the advantage that a loop test can be made on them, and also in over-all potential measurements the two wires running to each point can be placed in parallel, thus lowering the resistance. In most cases, however, we do not consider a pair of wires necessary.

X. COSTS

1. BASIS OF CALCULATION OF INSTALLATION COSTS

In determining the installation cost of the plan for electrolysis mitigation outlined above the following unit costs have been used:

(*a*) *Substation Equipment.*—Substation equipment, including rotary converters, transformers, switchboard panels, switches, and all necessary accessories, has been estimated at $30 per kilowatt rated capacity.

(*b*) *Buildings.*—Only one building is estimated for, and this is the proposed substation at Chestnut; the cost of this has been estimated at $1200, which seems a sufficient allowance for a small interurban substation located in the country as contemplated.

(*c*) *Grounds.*—In view of the location of the substation in the rural district, the estimate for land for the substation has been placed at $100, which is probably more than ample to cover the actual investment in ground that would be made.

(*d*) *Cost of Moving Direct-Current Feeder Cable.*—This cost includes only the labor charges and the materials for the stringing of the cable in the new location, the cost of the copper cable not being considered. This is because all of the copper proposed in the negative feeder system will be obtained by removing one of the present positive feeders, as already explained. This labor charge is estimated at $46 per 1000 feet of 300 000 circular mil cable.

(*e*) *Cost of Installation of High-Tension Transmission Line.*—The estimate for this is based on 13 000 volt three-phase transmission, using northern cedar poles with creosoted butts, No. 4 copper wires, and porcelain insulators, the poles being 35 feet long and set 40 poles to the mile. The estimate cost of this line

is \$1350 per mile, and as the line would probably run from the Rockport substation its length would be 9.5 miles.

(*f*) *Cost of Installing Resistance Tap.*—The four resistance taps used are estimated at \$30 each. This is based on the use of galvanized-steel cable wound on a frame and mounted on the pole near the point of connection to the feeder.

(*g*) *Cost of Installation of Potential Wires.*—The cost of installing these wires is taken at \$19 per mile, installed. This figure is based on the use of single No. 12 galvanized-iron wire mounted either on the poles carrying the direct-current feeders or on the trolley-span wires. The estimate allows \$9 per mile for materials, including porcelain insulators, and \$10 per mile for labor.

2. ANNUAL OPERATING COSTS

In determining the annual charges on the investment required by the proposed installation and other operating costs we have adopted the following figures: (*a*) Building: Interest, 5 per cent; depreciation, 4 per cent; taxes, 1 per cent; insurance, 1 per cent; total, 11 per cent. In determining the depreciation a life of about 17 years is assumed. We credit interest at 5 per cent, compounded annually, to the depreciation fund, and on this basis a life of 17 years corresponds to an annual depreciation rate of 3.87 per cent. The figure of 4 per cent, as here taken, is therefore quite ample to cover this item. (*b*) Ground: Interest, 5 per cent; taxes, 1 per cent; total, 6 per cent. (*c*) Equipment: Interest, 5 per cent; depreciation, 4 per cent; taxes, 1 per cent; insurance, 1 per cent; total, 11 per cent. (*d*) Cost of moving cable: Interest, 5 per cent; amortization, 2 per cent. The reason for not figuring depreciation, interest, and the taxes on the cost of the copper is that in this case we have simply moved the cable from one locality to another and use it as negative instead of positive feeder. The annual charge on the copper will therefore be substantially the same as it is under present conditions, and consequently there is no increased annual charge due to this item that is chargeable to the proposed method of mitigation. (*e*) High-tension transmission line: Interest, 5 per cent; depreciation, 3 per cent; taxes, 1 per cent; total, 9 per cent. The depreciation on certain portions of the transmission line, such as poles, insulators, etc., will be con-

siderably greater than the figure here given. However, a considerable part of the cost of the line is in No. 4 bare copper wire, on which the depreciation rate is very low, largely because of its relatively high scrap value. The 3 per cent here charged to depreciation is based on an average life of 20 years for the different component parts of the transmission line. (*f*) Potential wires: Interest, 5 per cent; depreciation, 7 per cent; taxes, 1 per cent; total, 13 per cent. The 7 per cent depreciation corresponds to a life of 11 years. (*g*) Resistance taps: Interest, 5 per cent; depreciation, 12 per cent; taxes, 1 per cent; total, 18 per cent. The high rate of depreciation here used is due to the fact that these resistance taps may have to be changed occasionally to accommodate the growth or redistribution of traffic. The 12 per cent charged represents a life of approximately 7 years. (*h*) Substation operation: The estimated cost of operating the proposed Chestnut substation is $1 800 per year. This is based on running the station on two shifts, with one man on each shift, and allowing $200 per year for incidental charges. (*i*) Cost of power: The cost of the energy lost in the positive and negative distribution is taken at 1.1 cents per kilowatt-hour and the economy estimated from reduction in energy losses are based on this figure. This is probably a lower figure than the actual cost to the company, so that the actual saving that would accrue will no doubt be considerably greater than these estimates, but we have based our estimates on this lower cost in order to be conservative and to give the railway company a good margin of safety.

3. SUMMARY OF INITIAL INVESTMENT AND OPERATING COSTS

Based on the foregoing unit costs, we determine the installation cost and annual operating costs as shown in Table 7. In this table the first column names the item in question, the second column gives the unit installation cost, the third column the total installation cost, the fourth column the rate of annual charge, and the last column the total annual cost. From this it will be seen that the total initial investment involved in making the proposed plan effective is $34 373, and the gross annual cost, including operation of the proposed substation, is $5248.90.

TABLE 7

Initial Investment and Annual Cost

Item	Unit cost	Initial invest-ment	Per cent annual charge	Annual cost
300-kilowatt substation equipment for Chestnut substation.	$30 per kilowatt	$9000.00	11	$990.00
300-kilowatt substation equipment for Penfield substation.	$30 per kilowatt	9000.00	11	990.00
Building for Chestnut substation		1200.00	11	132.00
Land for Chestnut substation		100.00	6	6.00
Nine and one-half miles of high-tension transmission line between Rockport substation and proposed Chestnut substation.	$1350 per mile	12 825.00	9	1154.25
Labor cost of moving and installing copper cable for insulated negative feeder, 42 780 feet of 300 000 circular mil cable.	$46 per 1000 feet	1968.00	7	137.75
Labor cost of connecting the two No. 0000 positive feeders to trolley every 1200 feet between Elyria power house and Ridgeville.	$1.50 each	55.00	7	3.85
Four resistance taps between tracks and insulated negative feeder.	$30 each	120.00	18	21.60
Potential wires for testing, 5.52 miles total*	$19 per mile	105.00	13	13.45
Operating of Chestnut substation: Labor, two men at $800 per year.				1600.00
Incidental expenses				200.00
Total		34 373.00		5248.90

*The potential wires for the Lake Shore Electric Railway, amounting to about 7800 feet, are not included in this cost estimate. Their cost would be about $26.

To offset these costs we have to consider the improvement in service conditions, the increase in reserve capacity, etc., as previously mentioned in this report, and in addition we must take account of the large saving in power costs that accompany the proposed change. It has already been shown that the total saving in power amounts to 70.4 kilowatts average for the 24-hour period, and at 1.1 cents per kilowatt hour the value of this is 77.40 cents per hour. Multiplying this by 8760, the number of hours in a year, we get a total annual saving of $6783.70 in energy. Deducting from this $5248.90, the total annual cost of the proposed changes as shown in Table 4, we find a net saving of $1534.80 per year. The proposed installation, therefore, would give (*a*) the desired results in the way of protection to the underground utilities in the city of Elyria, (*b*) a large net profit over and above the

proper annual charges on the installation cost, and (*c*) greatly improved operating conditions and reserve capacity in the power-distribution system, resulting in better and more reliable service and a large capacity for future growth of traffic without the necessity of increasing the substation equipment. It is evident, therefore, that the proposed changes would be desirable solely from the standpoint of satisfactory and economical car operation, and when we consider that at the same time electrolysis troubles in the city of Elyria would be so greatly reduced as to become practically negligible the proposed changes appear to be highly desirable from every point of view.

4. COMPARISON OF COST OF THE PROPOSED SYSTEM WITH THAT OF A NEGATIVE BOOSTER

In addition to the proposed installation, as outlined in an earlier part of this report, we have also considered carefully the advisability of installing a negative booster at the Elyria power house in lieu of the resistance tap between the negative bus and the rails at that point, the object being the possible saving of the power which under the proposed plan would be expended in the resistance tap. Careful calculations have shown, however, that the energy thus saved would be very slight, because of the large losses in the booster itself, operating, as it would, on a poor load factor. In fact, unless the current density in the cables is run nearly as low as under the proposed plan, the losses would be increased under the booster system, so that it would be impossible to save enough in the copper cost to pay for the booster equipment. The resistance tap is therefore not only more economical than the negative booster, but it is also much simpler, and should therefore be adopted.

XI. GENERAL SUMMARY

Reviewing briefly the ground discussed in some detail in the foregoing portions of this report, we find that the evidence at hand indicates that present electrolysis conditions in Elyria are unsatisfactory and that great reductions in the potential drops in the negative return must be made in order that damage to underground structures may be reduced to a reasonable minimum.

The most effective and logical way of protecting the underground structures is by applying remedial measures to the railway system itself, such measures being designed to reduce potential gradients to much lower values than those that prevail in Elyria at the present time. Inasmuch as it is not practicable to entirely eliminate the last trace of stray currents in the earth, it may be desirable in the case of lead cables to supplement the reduction of voltages in the negative return by a very limited amount of drainage, such drainage being no more than absolutely necessary to keep the cables from becoming positive to any dangerous extent to the surrounding structures. If the potential gradients specified in the above report, namely, 0.3 volt per 1000 feet average for the 24-hour period, be maintained, it is altogether improbable that any additional protection will be required on the underground pipe systems. In case such additional protection should be found desirable it should preferably be applied by breaking up the continuity of the pipe systems by inserting insulating or high-resistance joints at intervals rather than by applying the drainage system to such pipes. If the potential gradients are lowered to the point above recommended, only infrequent insulating joints will be necessary. As a matter of precaution these should be installed at intervals of a few hundred feet in all new work that is likely to be affected by stray currents, and they should also be installed in old-pipe networks wherever this can be done without material increase in expense—for example, when repairs to the lines are being made.

A study of the present distribution system shows that it is not economical to reduce the voltages in the negative return to the desired safe limit with the present arrangement of the positive feeding system. Moreover, the present conditions are such that it is not economical to continue operating under the present feeder system, while the maintenance of satisfactory car service with reasonable reserve capacity to guard against interruption of traffic requires that a substation be placed between Elyria and Rockport, as contemplated in the proposed plan. These changes consist in the installation of an additional substation between Elyria and Rockport, preferably in the vicinity of Chestnut. The capacity of this station should be about 300 kilowatts. An

increase in the capacity of the present Penfield substation is also necessary, an increase of 300 kilowatts being preferable, while at the same time arrangements should be made for feeding one-half of the Elyria-Penfield section from the Penfield substation.

It is also recommended, both for the purpose of reducing the potential drops in the negative return and for reducing the energy losses in the rails, to interconnect the tracks of the Cleveland, Southwestern & Columbus Railway to the Lake Shore Electric Railway where they approach closely to each other on Mill Street and on West Street.

A third measure consists in the installation of a negative return feeder system extending from the negative bus of the Elyria power house to the tracks on the Lake Shore Electric Railway at Lodi and Mill Streets with connections to the tracks of the Cleveland, Southwestern & Columbus Railway through suitable resistance taps at Broad and Court Streets, at the siding between Eighth and Ninth Streets, and at Sixteenth Street and at the negative bus.

As a further means of keeping a close watch on the voltage conditions existing in the negative return system, it is urged that a system of potential wires be run from some central point, preferably the passenger station on Court Street, to various remote points on the tracks of both railway lines. It is recommended that such wires be run from the passenger station and connected to the tracks at the following points: Broad and Court Streets, Lodi and Mill Streets, Sixteenth Street and Middle Avenue, Lake Avenue and corporation line, Cleveland Street and corporation line, Gulf and Cleveland Streets, and the intersection of the Lake Shore Electric Railway tracks with the corporation line.

With the changes in feeding distances, interconnection of tracks, and the installation of the negative return feeder system, as described above, the potential gradients in the negative return throughout the city of Elyria will be reduced to a value not exceeding 0.3 volt per 1000 feet average for the 24 hours. In order to accomplish this end it has been shown that the total initial investment required will be $34 373, which covers the cost of the new equipment required, building and ground for the proposed substation, the resistance taps for the negative feeder system, the potential wires for test purposes, and the

high-tension transmission line from Rockport to the proposed new substation. The installation of the proposed substation makes it desirable to remove one of the present positive feeders running from the Elyria power house to the vicinity of Ridgeville, and this supplies more than enough copper for the entire proposed negative return feeder system, so that no purchase of additional copper is contemplated. The total annual cost of the proposed changes, making due allowance for interest, depreciation, insurance, taxes, and extra operating expenses, amounts to $5248.90 per year. There results from the proposed changes, however, a power saving of 70.4 kilowatts average for 24 hours, which at the low estimate of 1.1 cents per kilowatt hour has an annual value of $6783.70, which is sufficient to pay all of the annual charges on the proposed installation, leaving a net profit of $1534.80 per year. In addition to this the reserve capacity of the power-supply stations will be increased by a total of 600 kilowatts. Further, the reduction of 70 kilowatts in the average power loss corresponds to a reduction in the peak-load loss of at least 200 kilowatts, so that the total net increase in reserve capacity of the power-supply system is about 800 kilowatts, all of which has a large cash value over and above the net profit as above estimated. In addition to this we have to consider the improvements in car service, resulting from better and more uniform voltage at the cars, giving more reliable service and better car lighting, while the shortening of the feeding distances gives much greater insurance for continuity of traffic because under the proposed plan the temporary shutdown of one station will not interfere with the car schedules to the extent that it would under present feeding conditions.

From the foregoing discussion it appears that the changes recommended in this report are highly important when considered solely from the standpoint of everyday operating conditions. The economies resulting are more than sufficient to pay all annual charges on the installation cost and leave a large net profit, in addition to reducing the potential gradients in the negative return to so low a value that damage from electrolysis will be negligible.

Washington, June 29, 1915.

After the above report was submitted to the city of Elyria, the railway company, and other utility companies concerned, negotiations were entered into between the city and the railway company as a result of which the railway company agreed to install completely the method of mitigation hereinabove recommended, and the railway company has agreed to have the provisions of this report incorporated into its franchise. That portion of the franchise referring to this subject reads as follows:

Said Company, by the acceptance of this franchise, hereby agrees to install and put into use within two (2) years from the acceptance hereof, all of the equipment, appliances and wiring to prevent electrolysis that was recommended by the Bureau of Standards of the United States Government in its report to said City dated June 26th, 1914, and now on file in the office of the Clerk of the Council of said City.

And said Company further agrees that, if at any time during the life of this franchise, the Council of said City shall, upon recommendation of said Bureau, require any change, addition, alteration, or omission in such equipment and appliances, that said Company will make such change, addition, alteration or omission within the time required by the Council of said City.

Certain recommendations made above have already been adopted and put into operation at the time this report goes to press, and it is understood that the remaining features will be adopted as soon as practicable. The Bureau of Standards will check up electrolysis conditions in Elyria from time to time with a view of determining definitely what conditions are after the new system has been completely installed.

[Continued from p. 2 of cover]

[NOTE.—A complete list of Circulars, Scientific Papers, and miscellaneous publications may be obtained free of charge on application to the Bureau of Standards, Washington, D. C.]